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Report No. CETHA-BC-CR-92017

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US Army Corps of Engineers

Toxic and Hazardous
Materials Agency

COPY 1

FEASIBILITY STUDY FOR THE EXPLOSIVES WASHOUT LAGOONS (SITE 4) SOILS OPERABLE UNIT UMATILLA DEPOT ACTIVITY (UMDA) HERMISTON, OREGON

Prepared For:

U.S. Army Toxic and Hazardous Materials Agency
(USATHAMA)
Contract No. DE-AC06-76RL01830

Prepared By:

CH2M HILL and MORRISON KNUDSEN
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April 1992

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This feasibility study (FS) for the Explosives Washout Lagoons (Site 4) Soils Operable Unit at the U.S. Army Depot Activity at Umatilla (UMDA) has been prepared to evaluate potential remedial alternatives for mitigating soil contamination at the site. It was conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). The FS provides a summary of remedial investigation information; a summary of the baseline risk assessment prepared by Dames & Moore; remedial action objectives; identification and screening of potentially viable technologies; and a detailed evaluation of alternatives assembled from the most promising technologies. The alternatives evaluated in detail are No Action, excavation followed by incineration, and excavation followed by composting. Incineration is a proven method of destroying explosives contaminants with an effectiveness greater than 99.99 percent. Composting is a method of biologically degrading explosives contaminants; although its application is innovative, extensive site-specific treatability studies indicate an effectiveness of 97 to 99 percent. Four potendial excavation scenarios, including a cleanup to background, were considered; these provided varying degrees of contaminant removal and risk (continued)

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reduction. The alternatives were evaluated for overall protection of human health and the environment; compliance with applicable or relevant and appropriate requirements (ARARs); long-term effectiveness; reduction of toxicity, mobility, and volume; short-term effectiveness; implementability; and cost. The No Action alternative failed to provide overall protection of human health and the environment and did not meet ARARs. Both incineration and composting provided overall protection and long-term effectiveness, met ARARs, and reduced soil toxicity. Incineration provides a somewhat greater degree of risk reduction than composting, but at approximately twice the cost.

Report No. CETHA-BC-CR-92017

US Army Corps of Engineers

Toxic and Hazardous Materials Agency

FINAL REPORT

FEASIBILITY STUDY FOR THE EXPLOSIVES WASHOUT LAGOONS (SITE 4) SOILS OPERABLE UNIT UMATILLA DEPOT ACTIVITY (UMDA) HERMISTON, OREGON

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April 1992

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April 2, 1992

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Dr. Mark Montgomery
Battelle Sacramento EMO
2701 Prospect Park Drive, Suite 110
Rancho Cordova, California 95670

Dear Dr. Montgomery:

Subject: Master Agreement 057970-A-D1; Task Order 142134 Explosive Washout Lagoons Site Support Services for Umatilla Depot Activity, Phase II Deliverables

Submitted herewith for your review are copies of the Explosives Washout Lagoons Draft Final Feasibility Study and Draft Final Proposed Plan. Copies have also been submitted to Dr. Charles Lechner of USATHAMA for his review.

At Dr. Lechner's request, we have concurrently sent review copies to the following:

- Mr. Mike Nelson
  Seattle District Army Corps of Engineers

- Mr. Harry Craig, USEPA
  Oregon Operations Office

- Mr. Bill Dana
  Oregon Department of Environmental Quality

- Mr. Mark Daugherty
  Umatilla Depot Activity

No schedule has been formally established for this review phase. However, Linda Mihalik will be meeting with Dr. Lechner, Mr. Craig, Mr. Dana, and Mr. Daugherty on April 8 to review comment incorporation. Following that, we would like any additional comments to be received by April 15, so that the documents can be published in final form for the public

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review period that will start on or about April 23. Because few additional changes to the documents are anticipated, Dr. Lechner has suggested that these draft final documents submitted herein might be used as the final documents, with individual pages substituted as necessary.

Written comments on the documents should be directed to the Commander, Umatilla Depot Activity, with a copy to Dr. Lechner at USATHAMA.

Please contact Bill Heartz or Linda Mihalik at (206) 453-5000 if there are any questions or we can be of further service.

Sincerely,

CH2M HILL

William T. Heartz

William T. Heartz
Task Order Manager

cc: Linda Mihalik/CH2M HILL/SEA
Dr. Charles Lechner/USATHAMA
Harry Craig/USEPA
Bill Dana/ODEQ
Mark Daugherty/UMDA
Mike Nelson/COE
Dan Glenn/CH2M HILL/RLO

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Acronyms and Abbreviations

APC	Air pollution control
ARARs	Applicable or Relevant and Appropriate Requirements
ATSDR	Agency for Toxic Substances and Disease Registry
BACT	Best available control technology
BCF	Bioconcentration factor
BRAC	Base Realignment and Closure
BW	Body weight
°C	Degrees Celsius
CA	Concentration in air
CAG	Carcinogen Assessment Group, EPA
CBG/WB	Cemented basalt gravel/weathered basalt
CDI	Chronic daily intake
CE	Combustion efficiency
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CF	Conversion factor
CFR	Code of Federal Regulations
CNS	Central nervous system
CO	Carbon monoxide
CS	Concentration in soil
CW	Concentration in water
CWA	Clean Water Act
2,4-DNT	2,4-Dinitrotoluene
2,6-DNT	2,6-Dinitrotoluene
DNB	1,3-Dinitrobenzene
DoD	Department of Defense
DRE	Destruction and Removal Efficiency

ED	Exposure duration
EF	Exposure frequency
EPA	U.S. Environmental Protection Agency
EPIC	Environmental Photographic Information Center
ET	Exposure time
FFA	Federal Facility Agreement
FI	Fraction ingested from contaminated source
FS	Feasibility study
HCl	Hydrochloric acid
HEAST	Health effects assessment summary tables
HI	Hazard Index
HMX	High melting explosive (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)
HRS	Hazard Ranking System
I	Intake
ID	Induced draft
IR	Ingestion or inhalation rate
IRIS	Integrated Risk Information System
IT	International Technology Corporation
K_d	Soil/water partition coefficient
K_{ow}	Octanol/water partition coefficient
LD_{50}	Lethal dose to 50 percent of the study population
LDR	Land disposal regulations
M	Million
MAIV	Mechanically agitated in-vessel
MCL	Maximum contaminant level
$\mu g/g$	Micrograms per gram (parts per million)
$\mu g/l$	Micrograms per liter (parts per billion)
mg/kg	Milligrams per kilogram (parts per million)
msl	Mean sea level

NB	Nitrobenzene
NCP	National Oil and Hazardous Substances Contingency Plan
NEPA	National Environmental Policy Act
NPL	National Priorities List
NSR	New source review
ODEQ	Oregon Department of Environmental Quality
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
PCB	Polychlorinated biphenyls
PCC	Primary combustion chamber
PIC	Products of incomplete combustion
PF	Potency factor
pg/m^3	Picograms per cubic meter
PHRED	Public Health Risk Evaluation Data Base
PMP	Potential Migration Pathway
POHC	Principal organic hazardous constituents
PPLV	Preliminary pollutant limit value
PSD	Prevention of significant deterioration
QA/QC	Quality Assurance/Quality Control
RA	Risk Assessment
RAC	Remedial Action Criteria
RAGS	Risk Assessment Guidance for Superfund
RAO	Remedial Action Objectives
RCRA	Resource Conservation and Recovery Act
RDX	Royal Demolition Explosive (hexahydro-1,3,5-trinitro-1,3,5-triazine)
RfD	Reference Dose
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RME	Reasonable maximum exposure

ROD	Record of Decision
RTECS	Registry of Toxic Effects of Chemical Substances
SARA	Superfund Amendments and Reauthorization Act
SCC	Secondary combustion chamber
SPPPLV	Single Pathway Preliminary Pollutant Limit Value
TBC	To be considered
TCLP	Toxicity characteristic leaching procedure
TDS	Total dissolved solids
TSD	Treatment, storage, and disposal
Tetryl	2,4,6-Tetranitro-N-methylaniline
THC	Total hydrocarbon concentration
TLV	Threshold Limit Value
TOC	Total organic carbon
TNB	1,3,5-Trinitrobenzene
TNT	2,4,6-Trinitrotoluene
TSS	Total suspended solids
TWA	Time-weighted average
TWA	Total Waste Analysis
UMDA	Umatilla Depot Activity
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency

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Executive Summary

Executive Summary

This feasibility study (FS) for the Explosives Washout Lagoons (Site 4) soil at the U.S. Army Umatilla Depot Activity (UMDA) in Hermiston, Oregon, has been prepared to evaluate potential remedial alternatives for mitigating soil contamination at the site. the Army is addressing soil contamination at the lagoons as an issue separate from groundwater contamination, since the latter is being addressed on an installation-wide basis. In addition, early remediation of the soil will minimize a potential continuing source of groundwater contamination.

Soil contaminated with explosives is encountered at numerous other military installations. The typical remediation consists of excavation followed by incineration, a highly effective although relatively high-cost technology. The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) has recently sponsored bench- and pilot-scale treatability studies demonstrating the effectiveness of explosives degradation via composting. Although an innovative technology for this application, composting has the potential for providing effective treatment at a moderate cost. The detailed evaluations in this FS focus on comparing composting, the innovative technology, against incineration, the demonstrated technology.

The FS was conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the

Superfund Amendments and Reauthorization Act of 1986 (SARA). Preparation of the FS was directed by USATHAMA for the Army as the owner/operator. Support was provided by the Environmental Protection Agency (EPA) Region X as the lead regulatory agency and the Oregon Department of Environmental Quality (ODEQ) as the support regulatory agency. The relationship and responsibilities of the three parties are outlined in the Federal Facility Agreement (FFA) executed by the U.S. Army, UMDA, EPA, and ODEQ, (EPA et al., 1989).

Following completion of this FS, USATHAMA, in consultation with EPA and ODEQ, will prepare a Proposed Plan (Plan) to describe the preferred remedy. The Plan will be issued by the Army, EPA, and ODEQ for public review. Following receipt and consideration of comments on the Plan, the Army and EPA will document the selected remedy in the Record of Decision (ROD), with the concurrence of ODEQ.

Site Description

History

UMDA is a 19,728-acre military facility located in northeastern Oregon, on the border of Morrow and Umatilla counties (Figure ES-1). It was established as an Army ordnance depot in 1941. Activities at the facility have included the storage of chemical-filled munitions and containerized chemical agents, and the disassembly, analysis, modification, reassembly, repacking, and storage of conventional munitions.

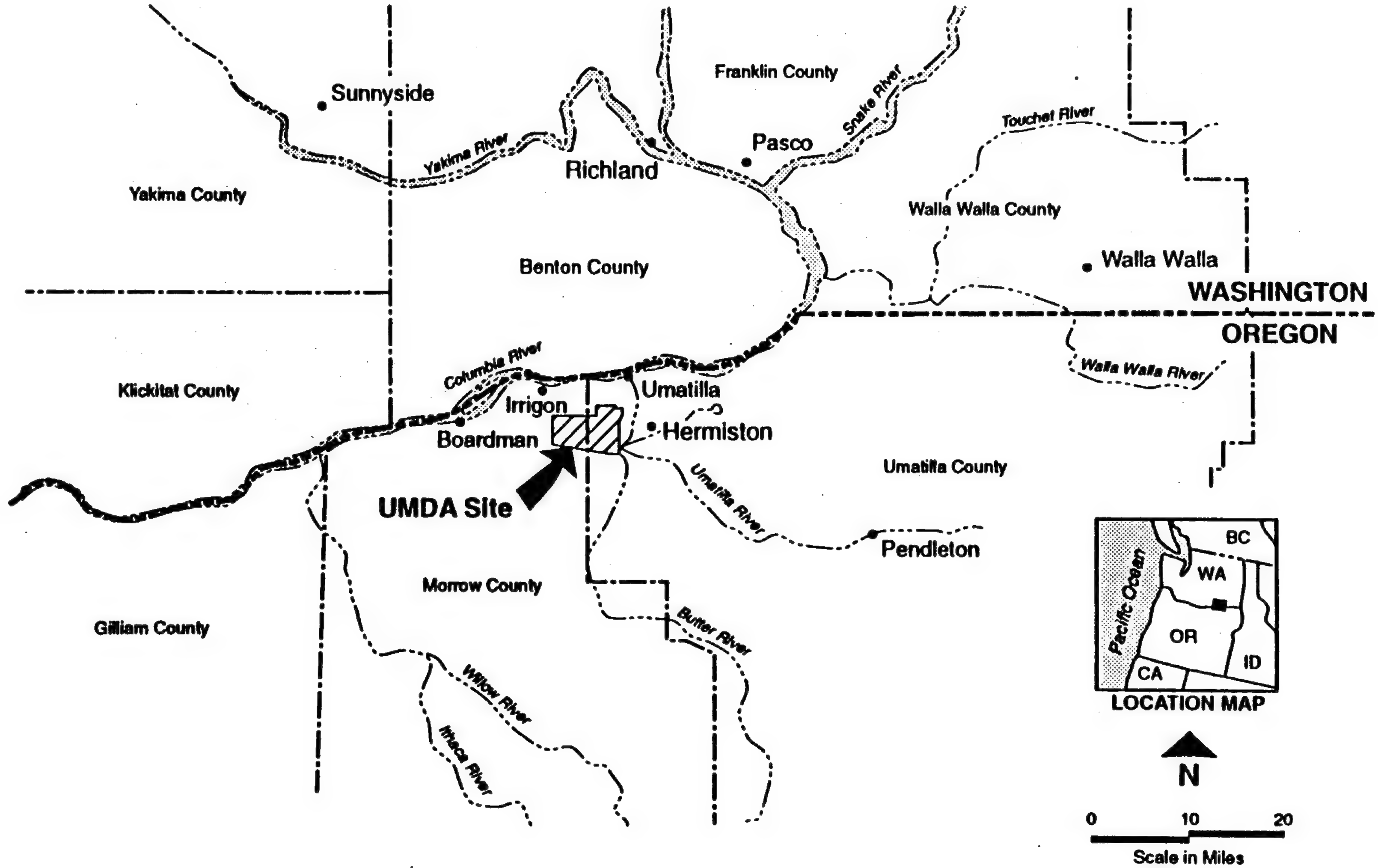

Figure ES-1
Facility Location Map
Umatilla Depot Activity

The UMDA facility is currently slated for realignment under the Department of Defense (DoD) Base Realignment and Closure (BRAC) program. When the Army eventually vacates the site, the facility could be released to private interests for either light industrial or residential use. Industrial use is considered to be the most likely future use scenario.

From the 1950s until 1965, UMDA operated an onsite explosives washout plant similar to that at other Army installations. The plant processed munitions to remove and recover explosives using a pressurized hot water system. The principal explosives consisted of the following:

- 2,4,6-Trinitrotoluene (TNT)
- Hexahydro-1,3,5-trinitro-1,3,5-triazine (commonly referred to as Royal Demolition Explosive or RDX)
- Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (commonly referred to as High Melting Explosive or HMX)
- 2,4,6-Tetranitro-N-methylaniline (Tetryl)

In addition, the munitions contained small quantities of 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), trinitrobenzene (TNB), dinitrobenzene (DNB), and nitrobenzene (NB) as either impurities or degradation products of TNT.

Operation of the plant included flushing and draining the explosives washout system weekly, and discharging the washwater to two adjacent infiltration lagoons located to the northwest of the plant. Residual explosives contained in the washwater were later found to have contaminated the soil and groundwater at the lagoons. The lagoons were placed on the National Priorities List (NPL) in 1987.

Physical Setting

Northeastern Oregon, the setting for UMDA, is characterized by a semi-arid, cold desert climate, an average annual precipitation of 8 to 9 inches, and a potential evapotranspiration rate of 32 inches. The facility is located on a regional plateau of low relief that consists of relatively permeable glaciofluvial sand and gravel overlying Columbia River Basalt. Groundwater occurs primarily in two settings: in an unconfined aquifer within the overlying deposits and weathered basalts, and in a vertical sequence of aquifers within the basalt. Groundwater depth and flow gradients in the vicinity are influenced by irrigation, pumping, and leakage from irrigation canals. The Columbia River runs in an east-west direction approximately 3 miles to the north of UMDA, and the Umatilla River runs south-north approximately 1 to 2 miles to the east. No natural streams occur within UMDA.

The lagoons, designated the north and south lagoons, are located in a depression in the central portion of UMDA as shown in Figure ES-2. The bottom dimensions of the north and south lagoons are approximately 39 by 80 feet and 27 by 80 feet, respectively. The lagoons are approximately 6 feet deep, with sandy bottoms and gravelly sides. They are separated by a gravel berm approximately 15 feet in width. The depth from the bottom of the lagoons to groundwater is approximately 45 to 50 feet.

Land and Water Use

The region surrounding UMDA is primarily used for irrigated agriculture. The population centers near UMDA include Hermiston (population 10,075), approximately 8 miles east; Umatilla (population 3,032), approximately 6 miles northeast; and Irrigon (population 820), 2 miles northwest. The total populations of Umatilla and Morrow Counties are approximately 59,000 and 7,650, respectively. Although access to the UMDA facility is currently restricted, potential future use includes light industry and residential development following realignment under the BRAC program.

Over 1,400 wells have been identified within a 4-mile radius of UMDA, the majority of which are used exclusively for domestic water. Three municipal water systems draw from groundwater within a 4-mile radius of UMDA, including Hermiston, Umatilla and Irrigon. In addition, groundwater serves as the primary source for irrigation. The

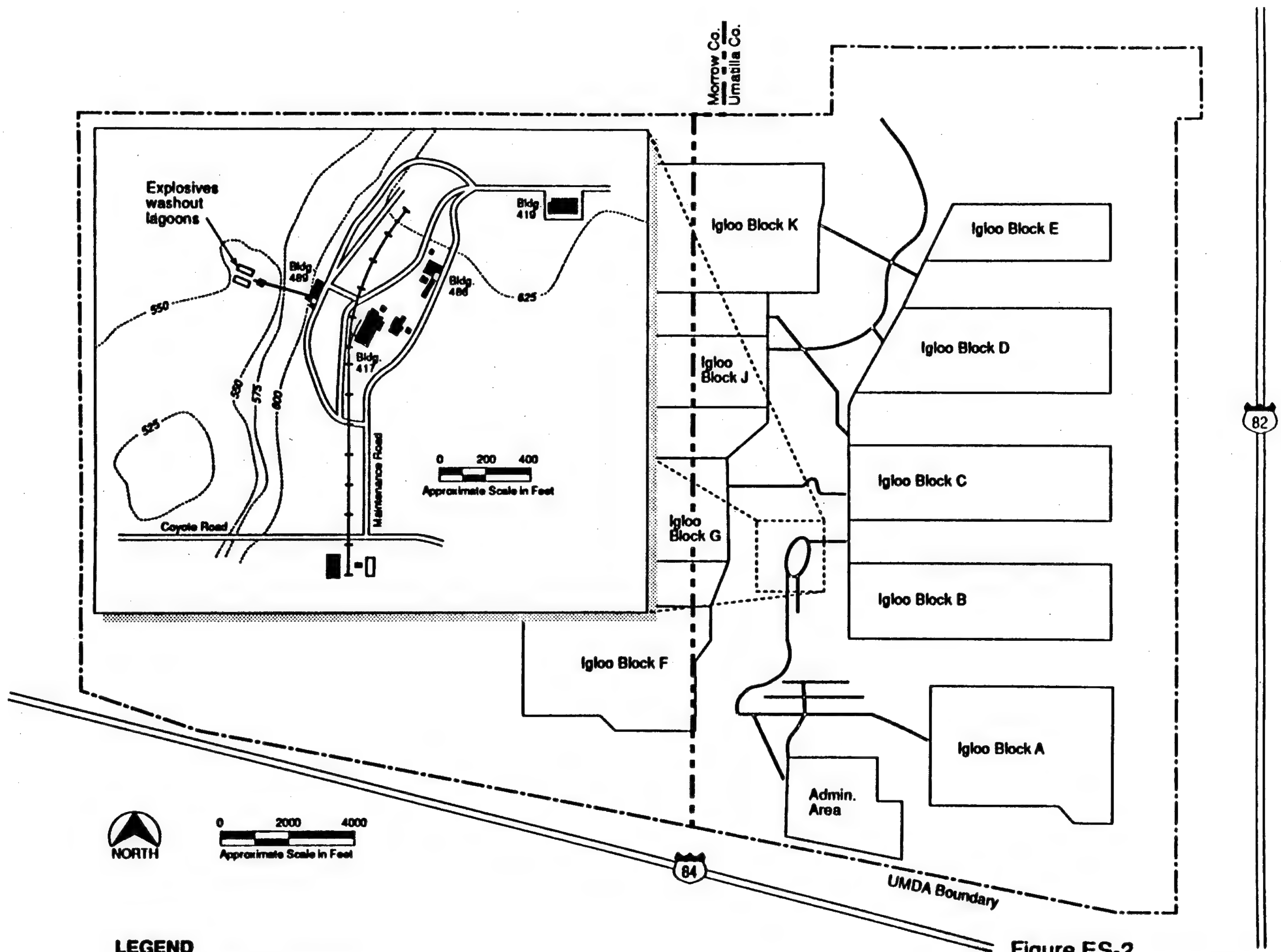

Figure ES-2
Location of Explosives Washout Lagoons

Columbia River is a major source of potable and irrigation water, and is also used for recreation, fishing, and the generation of hydroelectric power. The principal use of the Umatilla River is irrigation.

Nature and Extent of Contamination

Several soil and groundwater investigations have been conducted at the Explosives Washout Lagoons from 1981 to the present. Samples collected from soil borings drilled below and surrounding the lagoons have been used to determine the vertical and horizontal extent of soil contamination. A network of 34 groundwater monitoring wells has been used to identify and map groundwater contamination. The following observations and conclusions regarding soil contamination were drawn from the available data:

- The contaminants most frequently detected in the soil are TNT, RDX, HMX, TNB, and 2,4-DNT. Tetryl, 2,6-DNT, DNB, and NB are rarely if ever detected, and then only at low (less than 5 µg/g) concentrations. No additional organic compounds were detected, and inorganic compounds were within general soil background levels.

- Contamination is present throughout the vertical extent of the unsaturated soil column (vadose zone) directly beneath the lagoons. RDX and TNT concentrations typically range from 100 µg/g to 2,000 µg/g to a

depth of 3.5 feet, and are generally less than 30 μg/g below that. TNT concentrations exceeding 2,000 μg/g have been observed in the top inch of soil, with a maximum of 88,000 μg/g detected. HMX concentrations generally range from below detection (<1 μg/g) to 100 μg/g throughout the soil column. TNB concentrations vary from 2 μg/g to 47 μg/g throughout the soil column. 2,4-DNT is typically not observed in the upper 6 feet of soil; concentrations are relatively low throughout the remainder of the soil column (below detection [<1 μg/g] to 5 μg/g).

- An apparent subsurface "hot spot" with elevated 2,4-DNT and RDX (16 μg/g and 80 to 90 μg/g, respectively) concentrations occurs at a depth of 15 to 20 feet in the western end of the south lagoon.

- Except at the saturated soil interface, there appears to have been little lateral migration of contaminants through the vadose zone.

- TNT and RDX concentrations up to 5,500 μg/g have been observed in the central berm dividing the two lagoons. Explosives concentrations measured in the perimeter berms are less than 20 μg/g.

- There is widespread contamination of the alluvial aquifer, primarily by RDX; high concentrations of TNT and HMX are observed close to the lagoons.

- The observed RDX contaminant plume extends primarily to the southeast and southwest of the lagoons.

Baseline Risk Assessment

A human health risk assessment (RA) for the Explosives Washout Lagoons was prepared by Dames & Moore (1991) to assess future health risks posed by explosives-contaminated soils and groundwater in the absence of remediation. The RA was also used to identify safe residual explosives concentrations for reference during remediation. The RA focused on contaminated soil; groundwater was addressed only to the extent that soil contaminants might affect groundwater quality. Included in the RA was a detailed analysis of the sources, exposure pathways, potential receptors, and toxicity of contaminants of concern. Pathways considered were ingestion of, inhalation of, and direct contact with soil, and ingestion of groundwater.

The probability of current exposure of human receptors to the contaminants of concern at the Explosives Washout Lagoons was considered low because of access restrictions and was therefore not evaluated in the RA. The probability of future exposure of human receptors was considered high based on UMDA's inclusion in the BRAC program and the possibility that the UMDA property will become available for residential or light industrial use.

Potential human health risks were calculated using a reasonable maximum exposure based on contaminant concentrations observed in soil and groundwater samples collected during site investigations. Excess cancer risks were calculated based on exposure to TNT, RDX, and 2,4-DNT, the three contaminants identified as potential carcinogens and for which slope factors are available; all of the explosives contributed to the calculated noncancer risks. The cancer risks associated with existing contamination were determined to be 1.4×10^{-2} for a residential use scenario and 6.0×10^{-3} for an industrial use scenario. The noncancerous hazard indices were 4253 and 624 for residential and industrial use, respectively.

The NCP states that the generally accepted excess cancer risk is 1×10^{-4} to 1×10^{-6}, with 1×10^{-6} being the point of departure for evaluating remedial goals. For systemic toxicants, the accepted noncancer risk level is a hazard index of no greater than 1.0. Both of these values are exceeded in both the residential and industrial use scenarios. The contaminants posing the greatest risk are TNT, RDX, and 2,4-DNT.

An ecological risk assessment that includes the Explosives Washout Lagoons is being conducted as part of the installation-wide RI/FS for UMDA. Site-specific results are not yet available for this FS. However, it was noted that the bottoms and sidewalls of the lagoons and the berms enclosing them are devoid of vegetation, while the surrounding ground surface is well-populated by native plants. In addition, explosives concentrations in surface soils at the lagoons exceed those levels determined in laboratory and field studies to cause marked stress to vegetation.

Remedial Action Objectives

The findings regarding site contamination and human health risk indicate the need to remediate the soil at the Explosives Washout Lagoons for the future protection of human health and the environment. The following remedial action objectives (RAOs) were developed to achieve this:

- Remove soil containing potentially reactive concentrations of explosives.
- Reduce the total excess cancer risk in soils to which human exposure is likely to 1×10^{-6} if feasible.
- If 1×10^{-6} is not feasible, reduce risks to within the range of 1×10^{-4} to 1×10^{-6}, the final level to be determined based on a cost-benefit analysis

These RAOs are based on (1) the results of the investigations and risk assessments, (2) the requirements under CERCLA, (3) federal ARARs, and (4) the State of Oregon requirement for cleanup of contaminated sites to background, or if that is not feasible, to the lowest concentration that is protective of human health and the environment and is cost-effective.

Depth and Volume of Excavation

The depth and volume of excavated soil depend on the final evaluation of cost versus benefit. Four excavation depths were selected for analysis and costing. The depths, associated soil volumes, and reasons for selection are shown in Table ES-1.

Table ES-1
Depth and Volume of Excavation

Depth[a]	Volume[b]	Mass	Comments
2 ft	2,500 cy	3,700 tons	Would remove soil that contains potentially reactive concentrations of explosives.
5 ft[c]	4,700 cy	6,800 tons	Depth at which there is a marked decrease in the benefit to additional excavation. Soil from an average depth of 5 feet to the water table exhibits relatively constant low-level contamination.
20 ft	20,000 cy	30,000 tons	Would remove soil that could potentially be disturbed during future industrial or residential activities.
47 ft	32,000 cy	47,000 tons	Would remove all soil beneath and surrounding lagoons to water table, effectively removing all of soil contaminants and reducing excess cancer risk to 1×10^{-6} or less. Approximation of cleanup-to-background scenario.

cy = cubic yards
[a]Depth beneath lagoons. For depth from surrounding ground surface add 6 feet.
[b]Loose volume; includes removal of berms and a 20 percent bulking factor incurred during excavation.
[c]Average; individual locations might vary.

General Response Actions and Screening of Technologies

Broad categories of remedial measures, called general response actions, were identified as potential methods for achieving the RAOs. Each of the response actions had a corresponding set of remedial technologies and process options for implementing that action. The technologies associated with these response actions were screened to eliminate those that were clearly inappropriate based on technical implementability. The technologies and process options remaining after the initial screening were then evaluated briefly based on considerations of short- and long-term effectiveness, implementability, and cost.

The options screened included no action, monitoring, engineered cap, clean soil cover, vegetative cover, surface controls (e.g., water spray), excavation, solidification/ stabilization, thermal treatment (e.g., incineration), biological treatment (e.g., composting), and solvent extraction. The remedial options that were selected for further consideration were no action, monitoring, surface controls, a clean soil cover, a vegetative cover, excavation, treatment by composting, and treatment by rotary kiln incineration. These remedial actions were combined to form the following three alternatives:

- **Alternative 1: No Action**

- **Alternative 2: Incineration.** This alternative would include excavation of the contaminated soil with conventional excavation equipment, testing of the soil below the excavation to assure removal of contaminants to an acceptable level, onsite incineration, testing of treated soil to confirm effectiveness, and replacement of the treated soil in the excavation. Dust control would be used as necessary for worker safety during remediation. A clean soil cover would be placed over the top, and the area would be graded and revegetated.

- **Alternative 3: Composting.** This alternative would include excavation of the contaminated soil with conventional excavation equipment, testing of the soil below the excavation to assure removal of contaminants to an acceptable level, onsite composting, testing of the finished compost to confirm effectiveness, replacement of the composted soil in the excavation. Dust control would be used as necessary for worker safety during remediation. A clean soil cover would be placed over the top, and the area would be graded and revegetated.

Detailed Analysis of Alternatives

The selected alternatives were analyzed to provide information sufficient to allow selection of a site remedy. The first part of the analysis consisted of developing a process description of each alternative and evaluating each alternative against the following seven CERCLA-mandated criteria:

- Overall protection of human health and the environment
- Achievement of applicable or relevant and appropriate requirements (ARARs)
- Long-term effectiveness
- Short-term effectiveness
- Reduction in toxicity, mobility, or volume of contaminants
- Implementability
- Cost

(Two additional criteria, state and public acceptance, will be evaluated after review by those parties.)

Process descriptions for each of the alternatives are provided below preceded by a discussion of elements common to more than one alternative. Summaries of the criteria evaluations are given in Tables ES-2 through ES-4.

Common Elements. Both Alternatives 2 and 3 would involve removal and treatment of explosives-contaminated soil. Four potential excavation depths, listed in Table ES-1, were considered in the comparative analysis. The soil remaining in place after excavation would be analyzed to verify that residual contaminant concentrations in the soil and the associated risks are within acceptable levels and meet RAOs. Likewise, the treated soil would be analyzed to verify the effectiveness of the treatment in achieving the RAOs and treatment standards. Treated soil would be replaced in the excavation and topped by at least 2 feet of clean soil. Additional clean soil might be added as necessary to return the area to its natural contours, and the area would then be revegetated. Backfilling might be deferred temporarily if such deferral would facilitate groundwater investigations. The potential impact of residual soil contamination on groundwater will continue to be monitored as part of ongoing UMDA programs. None of the alternatives include future restrictions on land use.

Alternative 1: No Action

The No Action alternative serves as a common reference point for subsequent comparison with the other alternatives. No containment, removal, or treatment of the soil at the Explosives Washout Lagoons would occur, and no new controls would be implemented to prevent human exposure. However, the existing security provisions that limit public access would be continued at least until such time as the UMDA facility is released from military control. Also, the groundwater investigation that is being implemented separately would continue.

Some slow recovery of the soil might be expected as a result of natural degradation/ transport processes. Conditions do not favor natural recovery, and the time frame is expected to be greater than 25 years.

An evaluation of the No Action alternative against the NCP criteria is provided in Table ES-2.

Alternative 2: Onsite Rotary Kiln Incineration

Soil would be excavated to the selected depth using conventional construction equipment, then treated onsite in a mobile or transportable refractory-lined rotary kiln incineration. After incineration, the treated soil would be analyzed for explosives and returned to the lagoon excavation if concentrations are acceptable.

Two incinerator systems were considered: a 4-ton-per-hour mobile unit for a small-volume excavation, and a 20-ton-per-hour transportable unit for a large-volume excavation. Either system would consist of a mechanical feed system; a rotating cylindrical kiln; a secondary combustion chamber (afterburner); and an air pollution control system and stack. The destruction removal efficiency (DRE) of incineration for explosives in soil has been demonstrated at similar sites to be greater than 99.99 percent. This would reduce explosives concentrations to below 1 μg/g, or an excess cancer risk of less than 1×10^{-6} (both residential and industrial use scenarios).

Up to one year would be required to develop project requirements and procurements for an incinerator, prepare the site, and schedule a system for mobilization. Following that, the time required for mobilization, trial burns, and soil treatment would vary depending on the type of unit, feed capacity, and total soil volume. The time interval between initial mobilization and project completion could range from 12 to 29 weeks.

An evaluation of the incineration alternative against the NCP criteria is provided in Table ES-3.

Alternative 3: Onsite Composting

Contaminated soil would be excavated to the selected depth using conventional equipment, mixed with an organic amendment (manure and agricultural waste), and

composted. Explosives contaminants are biodegraded and biotransformed by the intense microbial activity stimulated during the composting process. The residual compost product would be analyzed for explosives, then returned to the lagoon excavation if concentrations are acceptable.

Two composting methods were evaluated, mechanically agitated in-vessel (MAIV) composting and windrow composting. In the former, composting would be conducted in a large tank equipped with mechanical mixers and air and water addition ports, which provide a well-aerated, climate-controlled environment for microbial activity. In windrow composting, the compost mixture would be formed into elongated piles (windrows) inside large greenhouse-type structures. The windrows would be aerated periodically by a mechanical turner designed to advance along the piles, fluffing them as it moves. To maintain the moisture content of the windrows, they would be sprayed with water as necessary.

Pilot-scale treatability studies indicate that the MAIV reduces TNT and RDX concentrations by greater than 99 percent and 97 percent, respectively. Windrow composting is expected to be comparably effective. This will be confirmed by ongoing treatability studies. Final contaminant concentrations for TNT and RDX are expected to be less than 30 μg/g each. The total excess cancer risk associated with these concentrations in soil is 4.5×10^{-6} (industrial use scenario) and 1.2×10^{-5} (residential use scenario). 2,4-DNT was not specifically evaluated in composting studies because of its already low and evenly distributed concentrations (an average of 1 μg/g throughout the top 20 feet

of soil), although laboratory studies indicate that it is susceptible to biodegradation. However, if 2,4-DNT at a concentration of 1 µg/g is included in the risk calculations, the total excess cancer risk would be 7.2×10^{-6} (industrial use scenario) and 1.8×10^{-5} (residential use scenario).

It is assumed that up to 1 year would be required to complete the ongoing windrow optimization study, develop procurements, and prepare the site for composting. Contaminated soil would be added to the compost system (either MAIV or windrows) at a rate of 20 cubic yards loose soil per day, 5 days per week; the compost matrix would require a residence time of 3 weeks in the MAIV and 45 days in the windrows. Assuming windrow composting, the operational time required to complete composting at the site would be approximately 32 weeks for a 2-foot excavation (2,500 cy); 54 weeks for a 5-foot excavation (4,700 cy); and 4 years for a 20-foot excavation (20,000 cy). In the latter case, a larger system would be more cost-effective and would require 25 months. Excavation to groundwater is not considered because composting would be of limited benefit for the low contaminant concentrations observed in deeper borings.

An evaluation of the composting alternative against the NCP criteria is provided in Table ES-4.

Comparative Analysis of Alternatives

A comparative analysis of the three alternatives is provided in Tables ES-5 and ES-6. Table ES-5 compares the extent to which the three alternatives meet the NCP selection criteria. Table ES-6 compares the residual risks and costs for various excavation depths and remedial alternatives.

Table ES-2
Summary of NCP Criteria Evaluation for No Action Alternative

Effectiveness						
Overall Protection	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction of Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Implementability**	**Cost**
Does not enhance protection of human health and environment. Current and future risks related to soil exposure remain essentially unchanged.	Does not comply with remedial requirements of the NCP or the State of Oregon.	Long-term effectiveness not achieved since future human exposure potential and environmental impacts not reduced. Continued potential for leaching of contaminants to groundwater.	No reduction in mobility or volume. Minimal natural reduction in toxicity.	No near-term activities planned at the site so little exposure to workers. Current access restrictions protect public. Continued absence of vegetation at lagoons.	Requires no active implementation. Difficult to justify to regulatory agencies and community.	Essentially zero in near-term. Probable long-term management and monitoring costs.

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Table ES-3
Summary of NCP Criteria Evaluation for Onsite Rotary Kiln Incineration Alternative

Effectiveness						
Overall Protection	Compliance with ARARs	Long-Term Effectiveness	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Implementability	Cost
Protection of human health achieved by reducing explosives concentrations to below detection limits (excess cancer risk $<1 \times 10^{-6}$, residential use scenario) and by treatment and monitoring of incineration emissions. Protection of environment achieved by reducing explosives concentrations to below those that cause significant plant stress.	Accomplished with >99.99 percent DRE of explosives and testing of treated soil before backfilling lagoons.	Effectiveness is permanent and long-term; contaminants are destroyed with a 99.99% efficiency. No long-term management required.	Destruction of contaminants reduces toxicity associated with explosives to essentially zero. Stack emissions expected to be very low toxicity. Treated soil not expected to be hazardous.	Workers, environment, and community protected during operations by using proper safety procedures and process monitoring. Time to implement and complete remediation 15 to 19 months.	Mobile and transportable rotary kiln incinerators are readily available and have been used at other explosives-contaminated soil sites.	2-ft. excavation: $2,730,000 5-ft. excavation: $4,470,000 20-foot excavation: $8,290,000 47-foot excavation $14,000,000

Table ES-4
Summary of NCP Criteria Evaluation for Windrow Composting Alternative

Effectiveness						
Overall Protection	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction of Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Implementability**	**Cost**
Protection of human health achieved by reducing explosives concentrations to protective levels (excess cancer risk 1.8×10^{-5}, residential use scenario). Protection of environment achieved by reducing plant stress associated with high explosives concentrations.	Accomplished by reduction of contaminants to lowest protective levels using cost-effective methods.	Effectiveness is expected to be long-term, since degradation products either mineralize or bind covalently into macromolecules. Contaminant concentrations reduced 97 to 99%.	Composting reduces soil toxicity as measured by bacterial mutagenicity and aquatic toxicity by 88 to 98%. Residual material is nutrient-rich compost. No other waste streams are produced.	Protection of workers, environment, and community during operations is accomplished with proper safety procedures and process monitoring. Time to implement and complete remediation 20 to 36 months.	Composting is commonly used in other applications. Site-specific treatability studies indicate successful application to UMDA soil and contaminants. Materials of construction and compost amendments readily available in area.	2-ft. excavation: $1,430,000 5-ft. excavation: $1,960,000 20-ft. excavation: $6,180,000

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Table ES-5

Cost and Effectiveness of Alternatives as a Function of Excavation Depth

Alternative	Mass (tons)	Excess Cancer Risk Prior to Remediation[a]		Excess Cancer Risk Following Remediation[a]				Total Cost ($000)	Cost (present worth, $000)
				Excavated/Treated Soil		Soil Remaining Below Excavation Depth[d]			
		Industrial Use Scenario	Residential Use Scenario	Industrial Use Scenario	Residential Use Scenario	Industrial Use Scenario	Residential Use Scenario		
No Action	NA	4.7×10^{-3}	1.0×10^{-2}	NA	NA	4.7×10^{-3}	1.0×10^{-2}		0
Incineration									
2-foot excavation	3,700	4.7×10^{-3}	1.0×10^{-2}	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	8.0×10^{-5}	2.1×10^{-4}	2,730	2,540
5-foot excavation	6,800	4.7×10^{-3}	1.0×10^{-2}	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	7.2×10^{-6}	1.8×10^{-5}	4,470	4,120
20-foot excavation	30,000	4.7×10^{-3}	1.0×10^{-2}	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	7.2×10^{-6}	1.8×10^{-5}	8,290	7,650
47-foot excavation[b]	47,000	4.7×10^{-3}	1.0×10^{-2}	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	14,000	12,800
Composting—Windrows									
2-foot excavation	3,700	4.7×10^{-3}	1.0×10^{-2}	7.2×10^{-6}	1.8×10^{-5}	8.0×10^{-5}	2.1×10^{-4}	1,430	1,370
5-foot excavation	6,800	4.7×10^{-3}	1.0×10^{-2}	7.2×10^{-6}	1.8×10^{-5}	7.2×10^{-6}	1.8×10^{-5}	1,960	1,870
20-foot excavation	30,000	4.7×10^{-3}	1.0×10^{-2}	7.2×10^{-6}	1.8×10^{-5}	7.2×10^{-6}	1.8×10^{-5}	6,180	5,590
47-foot excavation[c]	NA	4.7×10^{-3}	1.0×10^{-2}	NA	NA	NA	NA	NA	NA
Composting—MAIV									
2-foot excavation	3,700	4.7×10^{-3}	1.0×10^{-2}	$<7.2 \times 10^{-6}$	$<1.8 \times 10^{-5}$	8.0×10^{-5}	2.1×10^{-4}	2,410	2,320
5-foot excavation	6,800	4.7×10^{-3}	1.0×10^{-2}	$<7.2 \times 10^{-6}$	$<1.8 \times 10^{-5}$	7.2×10^{-6}	1.8×10^{-5}	3,270	3,100
20-foot excavation	30,000	4.7×10^{-3}	1.0×10^{-2}	$<7.2 \times 10^{-6}$	$<1.8 \times 10^{-5}$	7.2×10^{-6}	1.8×10^{-5}	9,910	8,200
47-foot excavation[c]	NA	4.7×10^{-3}	1.0×10^{-2}	NA	NA	NA	NA	NA	NA

[a]Risk based on direct contact with soil: ingestion, inhalation, dermal contact.
[b]This scenario reflects cleanup to background. All contaminated soil would be treated.
[c]A combination of composting and a 47-foot excavation was not evaluated. The deep excavation is intended to reflect cleanup to background and cannot be achieved by composting.
[d]Risk calculations based on average TNT, RDX, and 2,4-DNT concentrations measured at indicated depth.
NA = Not applicable to this alternative.
cy = Cubic yards.

Table ES-6
Comparative Evaluation of Alternatives

Effectiveness						
Overall Protection	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction of Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Implementability**	**Cost**
Alternatives 2 and 3 provide overall protection of human health and the environment in accordance with the NCP by reducing the excess cancer risk to $<1 \times 10^{-6}$ and 2×10^{-5}, respectively (residential use scenario); both significantly reduce plant stress associated with very high explosives concentrations; some reduction in growth height may still be observed in Alternative 3. Alternative 1 provides no protection for future users of the site, does not enhance protection of the environment, a:d is not addressed further in this table.	Alternatives 2 and 3 comply with all ARARs. In accordance with state requirements for remedial actions, the risk reduction benefits for variations on each alternative are shown as a function of cost.	Long-term effectiveness is achieved in Alternative 2 by the permanent destruction of 99.99 percent of contaminants. Alternative 3 achieves long-term protection by degrading contaminants by 97 to 99 percent.	Excavation to 5 feet below the lagoons reduces excess cancer risk by about 99.8 percent from initial levels. This increases to 99.9 percent at 20 feet and 100 percent at 47 feet. Both Alternatives 2 and 3 reduce contaminant concentrations in excavated soils, thereby reducing toxicity. Alternative 2 reduces toxicity by >99 percent. Alternative 3 reduces toxicity by 88 to 98 percent.	Both Alternatives 2 and 3 use appropriate controls to provide near-term protection of the public, onsite workers, and the environment during remedial activities. Alternative 2 could be implemented and completed within 15 to 19 months. Alternative 3 could be implemented and completed in 20 to 36 months.	Implementability of Alternative 2 has been demonstrated for similar contaminants at other sites. Alternative 3 is innovative, but supported by site-specific treatability studies. There appear to be no obstacles to obtaining necessary materials and agency approval.	Costs for a 47-foot excavation with treatment by incineration (Alternative 2, (cleanup-to-background) are $14 M. For other excavation depths, Alternative 3 is less expensive, especially for low-volume remediation (e.g., for a 5-foot excavation, costs are $2 M for composting and $4 M for incineration).

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Introduction

Chapter 1

Introduction

This feasibility study (FS) for the Explosives Washout Lagoons (Site 4) soil at the U.S. Army Depot Activity at Umatilla (UMDA) has been prepared by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) to evaluate potential remedial alternatives for mitigating soil contamination at the site. The FS was conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). CERCLA, commonly referred to as Superfund, provides for the cleanup of inactive waste disposal sites. Implementation of the CERCLA remediation process is outlined in Title 40 of the Code of Federal Regulations (40 CFR) Part 300, National Oil and Hazardous Substance Contingency Plan (NCP). As part of the process, a remedial investigation and feasibility study (RI/FS) is typically performed at the site. The objective of the RI/FS is "to gather information sufficient to support an informed risk management decision regarding which remedy appears to be most appropriate for a given site" (Environmental Protection Agency [EPA], 1988).

1.1 Purpose and Scope

UMDA is a U.S. Army ordnance depot located near Hermiston, Oregon. From the 1950s until 1965, UMDA operated an Explosives Washout Plant onsite to remove and recover explosives from munitions. The washout system was flushed and drained on a weekly basis, and the washwater was discharged to two infiltration lagoons. Residual explosives contained in the washwater contaminated the soil and groundwater at the lagoons. After a Hazard Ranking System (HRS) evaluation was performed at the site, the lagoons were placed on the National Priorities List (NPL) in 1987 and became subject to the requirements of the NCP.

The risks associated with future exposure to the contaminated soil exceed NCP guidelines and indicate that remediation is required. In addition, the soil might currently be a secondary source of groundwater contamination. To facilitate management of the lagoons' remediation and to provide early control of the contamination source, UMDA has elected to address soil and groundwater issues separately. This FS defines the soil contamination problems at the Explosives Washout Lagoons; formulates objectives for soil remediation; and identifies, develops, screens, and evaluates soil remedial action alternatives. The results of the evaluation will be used by the Army, in consultation with EPA and the Oregon Department of Environmental Quality (ODEQ), to select and propose a preferred remedial action for the lagoons. After the Proposed Plan is reviewed by the public, the Army and EPA will formalize the soil remedial action decision in a Record of Decision (ROD) document with concurrence from ODEQ. A

similar process is planned to address groundwater contamination and other UMDA soil contamination sites on an installation-wide basis.

Soil contaminated with explosives is found at numerous Army installations. To date, the standard method of remediating these soils has been excavation and incineration, a relatively high-cost but effective treatment method (International Technology Corp. [IT], 1987). In the early 1980s, USATHAMA initiated treatability studies on the effectiveness of an alternative remediation method that consists of combining explosives-contaminated soil with suitable organic amendments and composting the mixture. Composting is a common method of biodegrading wastewater sludges, yard and agricultural wastes, and similar organic-contaminated wastes, but its application to explosives is innovative.

The NCP encourages the evaluation of innovative technologies where they might offer the "potential for comparable or superior treatment performance or implementability, fewer or lesser adverse impacts... or lower costs for similar... performance than demonstrated technologies" [40 CFR 300.430(a)(1)(iii)(E)]. Because of the success achieved in the composting treatability studies and the potential for lower costs, this FS focuses on evaluating composting against the more well-established technology of incineration. As a baseline for both technologies, the impacts of taking no action at the site are also presented. Other potentially applicable remedial technologies are discussed briefly in the technology screening.

This FS is also intended to satisfy the requirements of section 102(2)(C) of the National Environmental Policy Act of 1969 (NEPA). The FS evaluates both the short- and long-term environmental impacts of several alternatives, including no action. In addition, a NEPA-type public review will take place after completion of the FS and Proposed Plan and prior to issuance of the ROD.

1.2 Organization

As the first step in the FS process, existing data and information on UMDA and the Explosives Washout Lagoons were compiled, summarized, and interpreted. These data and information are presented in Chapter 2. They serve to establish a historical perspective of the site and provide an understanding of the nature and extent of the existing contamination problem. In addition, they were the basis for a preliminary risk assessment, the results of which are also presented in Chapter 2.

Based on the interpretations and analyses of the site data, remedial action goals and objectives were defined, and possible general response actions and associated technologies were identified. The response actions and technologies were screened, first for general feasibility, then in more detail on the bases of effectiveness, implementability, and cost. Those technologies that survived the screening were assembled into remedial alternatives. The remedial goals and objectives and the results of the screening analysis are presented in Chapter 3.

The three alternatives assembled following the screening were evaluated in greater detail. A process for implementing each alternative was developed, and each alternative was considered in terms of how well it would meet the evaluation criteria specified in the NCP. After the individual evaluations, the alternatives were compared against each other to identify strengths and weaknesses. These evaluations are presented in Chapter 4.

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Summary of Remedial Investigation

Chapter 2

Summary of Remedial Investigation

This section describes the background and physical setting of UMDA and the Explosives Washout Lagoons, including the nature and extent of the existing soil contamination problems at the lagoons. The primary references for this are the installation-wide Preliminary Assessment and RI conducted by Dames & Moore (1990a, 1990b, 1992) and the supplemental investigation conducted at the lagoons by Morrison Knudsen Environmental Services and CH2M HILL (MKES/CH2M HILL, 1992). Following this description is a summary of the baseline risk assessment performed by Dames & Moore (1991).

2.1 Location and History

UMDA is located in northeastern Oregon on the border of Umatilla and Morrow counties near the city of Hermiston as shown in Figure 2-1. It was established by the Army in 1941 as an ordnance facility for storing conventional munitions. Subsequently, the function of the facility was extended to include ammunition demolition (1945), renovation (1947), and maintenance (1955). In 1962, the Army began to store chemical-filled munitions and containerized chemical agents at the facility. UMDA

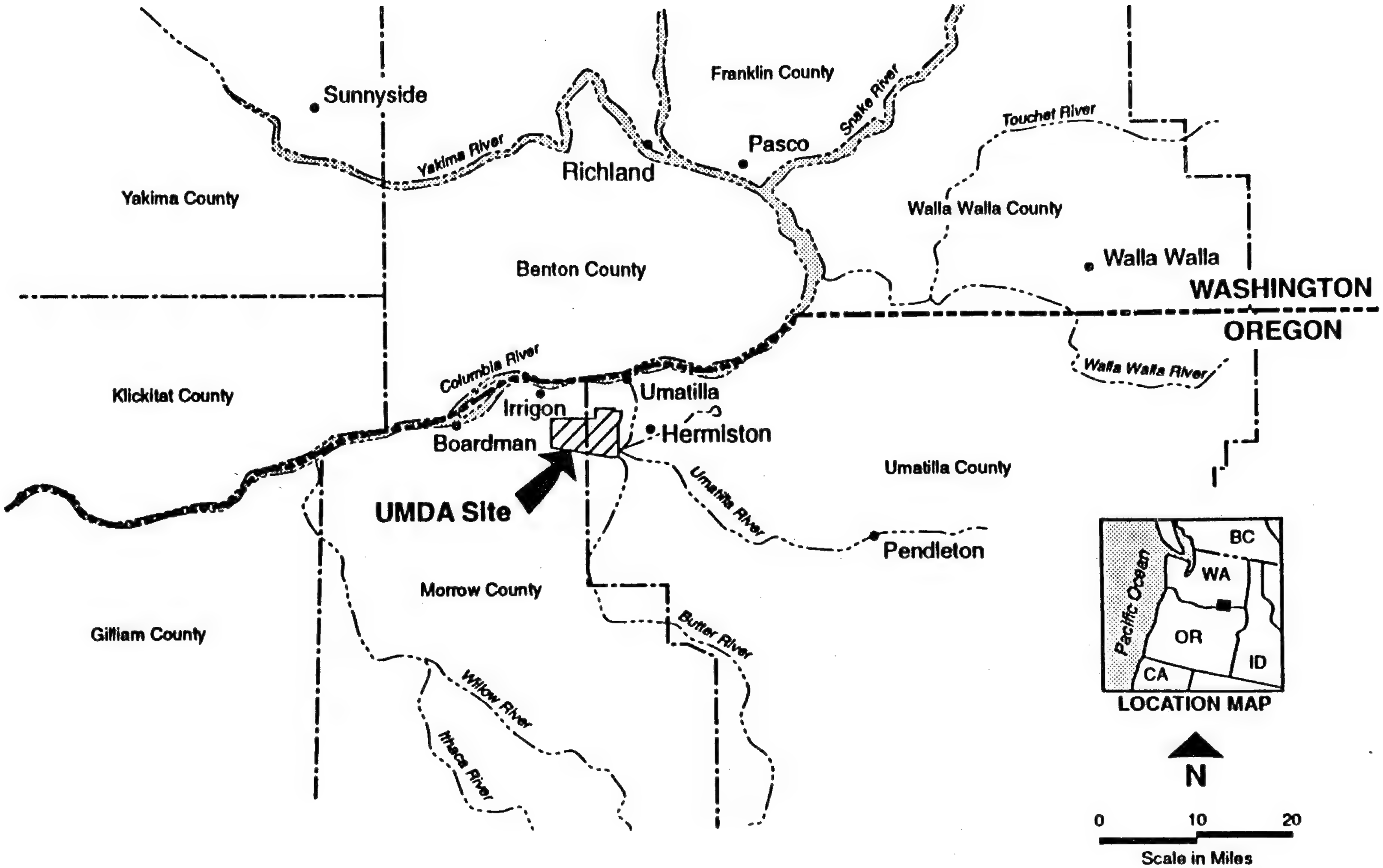


Figure 2-1
Facility Location Map
Umatilla Depot Activity

continues to operate today as a munitions storage facility, and will be conducting activities associated with the chemical demilitarization program and site remediation.

The facility occupies a roughly rectangular area of 19,728 acres; 17,054 acres are owned by the U.S. Government, while the remainder are controlled by restrictive easements that provide a safety zone around the facility (Dames & Moore, 1990a). Although ownership of the latter is private, the easements grant perpetual rights to the U.S. Government, including the right to prohibit human habitation and to remove buildings. The owners retain the right to farm the lands and to graze livestock.

The UMDA facility is currently one of several installations scheduled for realignment under the Department of Defense (DoD) Base Realignment and Closure (BRAC) program. Under this program, the Army will eventually vacate the site and relinquish ownership to another governmental agency or private interests. Although future use of the site beyond that time has not been determined, either light industrial or residential use is a possibility. Industrial use is considered to be the most likely future use scenario.

2.1.1 Operational History of the Explosives Washout Lagoons

Explosives washout operations were conducted in the Explosives Washout Plant (Building 489) at UMDA from the early 1950s until 1965 (Dames & Moore, 1990b). The

washout process involved removing explosives from obsolete munitions, bombs, and projectiles by applying pressurized hot water or steam. The resulting slurry was transferred to tanks located in the plant, where sludge containing the explosives was collected and later reclaimed.

The explosive compounds thus processed consisted mainly of the following:

- 2,4,6-Trinitrotoluene (TNT)
- Hexahydro-1,3,5-trinitro-1,3,5-triazine (commonly referred to as Royal Demolition Explosive or RDX)
- Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (commonly referred to as High Melting Explosive or HMX)
- 2,4,6-Tetranitro-N-methylaniline (Tetryl)

In addition, the munitions contained small quantities of 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), 1,3,5-trinitrobenzene (TNB), 1,3-dinitrobenzene (DNB), and nitrobenzene (NB), occurring as either impurities or degradation products of TNT.

The water used in the washout process was recycled during operation. However, approximately once a week the washout system was drained and flushed, producing

approximately 150,000 gallons of effluent containing explosive contaminants (Dames & Moore, 1990a) that were discharged to nearby lagoons. Historical photographs indicate that construction of a single lagoon began sometime about 1950; by 1958, the lagoon had been divided into two adjacent rectangular lagoons (Dames & Moore, 1992) (see Figures 2-2 and 2-3). The lagoons were fed by a metal trough that terminated in a movable flume. The flume allowed the lagoons to be used on an alternating basis, with one lagoon in use while the other dried. A total of up to 85,000,000 gallons of effluent is estimated to have been discharged to the lagoons during the period of plant operation (Dames & Moore, 1990a).

The effluent seeped into the ground or evaporated, leaving a sludge that was periodically removed and transported to the ammunition demolition area for burning. Sludge also accumulated in and was removed from an in-line concrete settling sump located along the trough between the Explosives Washout Plant and the lagoons. The lagoons were reconstructed over the years, perhaps several times (Dames & Moore 1990a). Washout operations ceased in 1965 and use of the lagoons was discontinued.

2.1.2 Regulatory History of the Explosives Washout Lagoons

An initial installation assessment was performed in 1978 and 1979 to evaluate environmental quality at UMDA with regard to the past use, storage, treatment, and disposal of toxic and hazardous materials. Based on imagery analysis provided by EPA's Environmental Photographic Interpretation Center (EPIC) as part of the assessment,

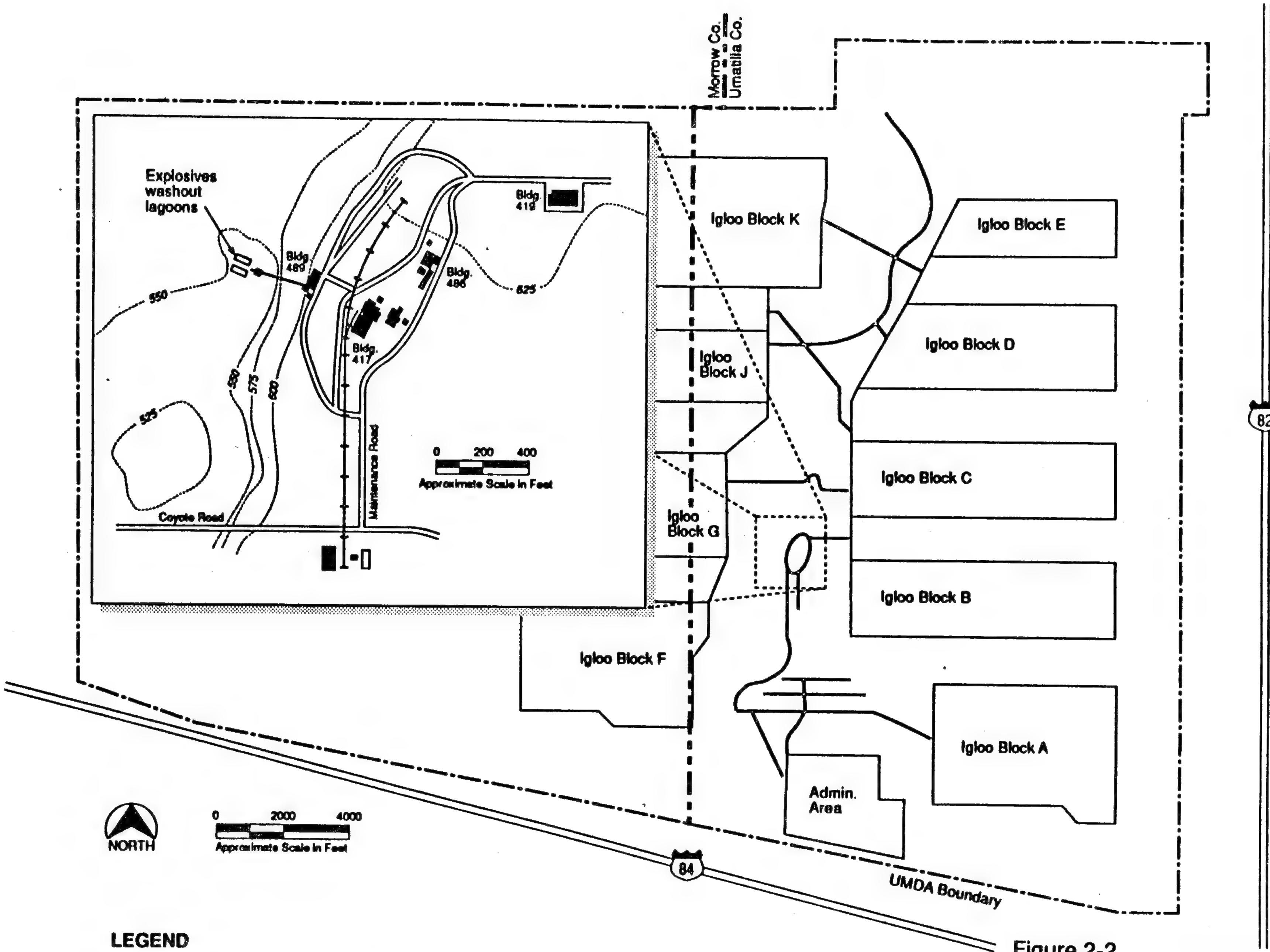


Figure 2-2
Location of Explosives Washout Lagoons

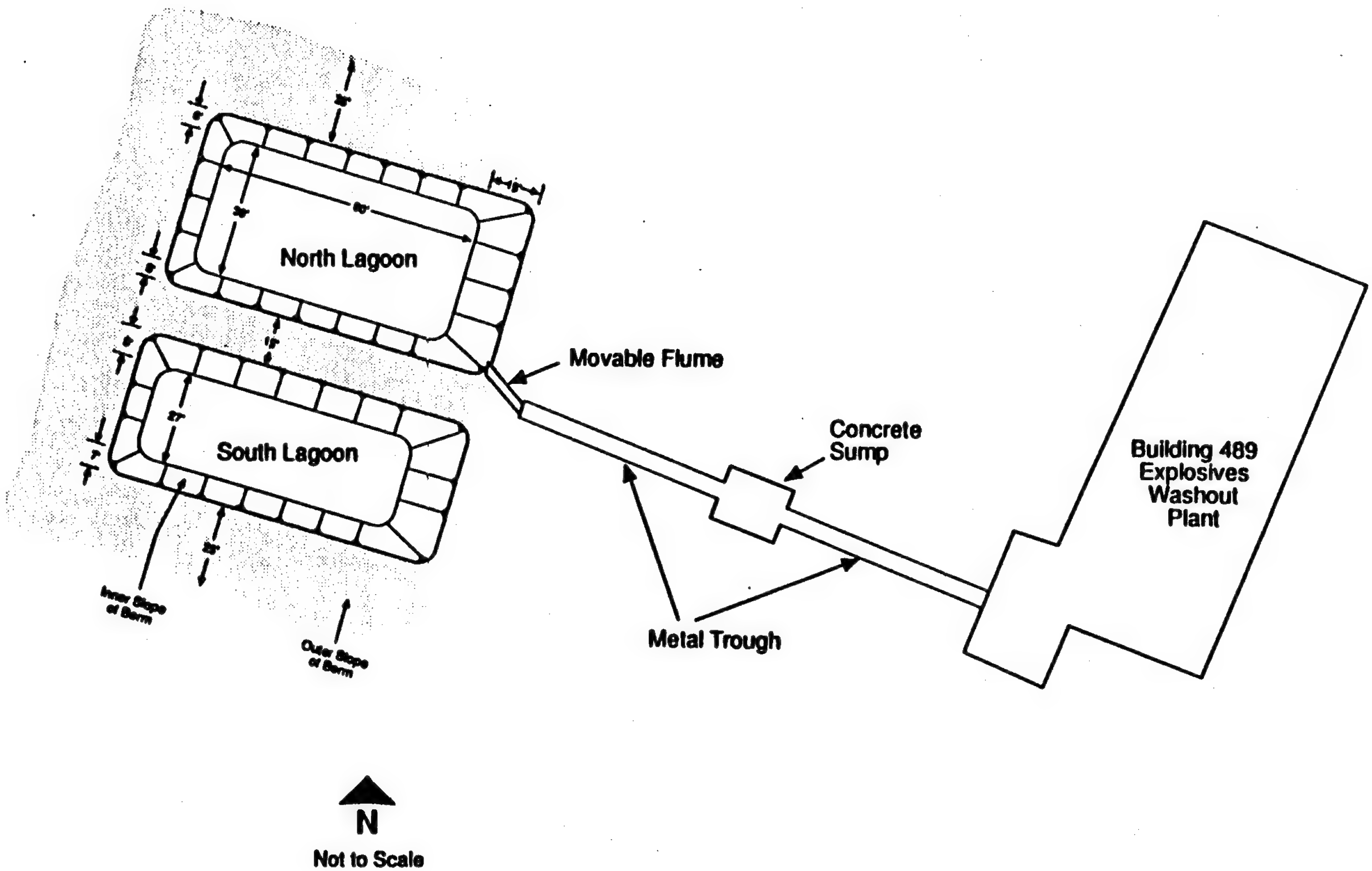


Figure 2-3
Explosives Washout Lagoons and Washout Plant Area

the Explosives Washout Lagoons (Site 4) were characterized as a potentially hazardous site (EPA, 1981). In 1981, Battelle conducted an Environmental Contamination Survey and Assessment at UMDA and identified what appeared to be a 45-acre plume of RDX in the shallow aquifer underneath the Explosives Washout Lagoons (EPA et al., 1989). Battelle concluded that discharges to the lagoons had caused contamination of the alluvial aquifer (Dames & Moore, 1990a). Subsequent investigations confirmed the presence of explosives in the soil and groundwater.

In 1984, the Explosives Washout Lagoons were evaluated using the HRS and received a score in excess of 28.5 (Dames & Moore, 1990a). As a result, the lagoons were proposed for inclusion on the NPL in 49 Fed. Reg. 40320 (October 15, 1984). They were formally listed on the NPL in Fed. Reg. 27620 (July 22, 1987) based on the HRS score and the results of the installation Resource Conservation and Recovery Act (RCRA) Facility Assessment.

On October 31, 1989, a Federal Facility Agreement (FFA) was executed by UMDA, the Army, EPA Region X, and ODEQ (EPA et al., 1989). One of the purposes of the FFA was to establish a framework for developing and implementing appropriate response actions at UMDA in accordance with CERCLA, the NCP, and Superfund guidance and policy. Remediation of contaminated soil and groundwater at the lagoons was a task identified within this framework.

2.2 Site Description

The lagoons, designated the north and south lagoons, are located west of Rim Road and north of Coyote Road at the base of Coyote Coulee, in the central portion of UMDA as shown in Figure 2-2. The bottom dimensions of the north and south lagoons are approximately 39 by 80 feet and 27 by 80 feet, respectively (USATHAMA, 1991a). Both lagoons are approximately 6 feet deep, with sandy-to-gravelly bottoms and gravelly sides that form slightly raised berms around the perimeter. The sides are sloped at approximately 35 degrees. The two lagoons are separated by a gravel berm approximately 15 feet in width across the top (USATHAMA, 1991a).

The lagoons were constructed within relatively permeable glacial flood gravels, and the soil immediately beneath the lagoons consists of admixtures of sand and gravel (MKES/CH2M HILL, 1992). The sand varies from fine to coarse, well-graded to poorly-graded, and clean to silty. The gravel fraction is typically fine-grained and subangular, with particle diameters of 1/4 to 1/2 inch. Minor amounts of silt are encountered as occasional thin seams ranging from 1 inch to 24 inches thick and as admixtures with the sand and gravel. Below the groundwater interface, the alluvium grades to gravel and eventually to gravelly silts or clayey silts at the bottom of the alluvial unit (Dames & Moore, 1992).

The soil underlying the lagoons was deposited in a fluvial environment. The lack of coarse gravel, cobbles, and boulders, and the presence of silt suggest an area of quiet deposition as compared to the torrential flood gravels deposited elsewhere at the UMDA. In borings completed in early November 1991, the unconfined groundwater table was encountered at depths of 47 to 48 feet below the bottom of the lagoons (MKES/CH2M HILL, 1992). The depth to groundwater has been observed to fluctuate on a seasonal basis (Dames & Moore, 1992).

Vegetation is absent on the gravel berms and within the lagoons themselves. In the area around the lagoons, vegetation is relatively sparse and consists largely of desert grasses and a few low bushes.

2.3 Regional and Area Setting

This section includes background information on regional climatic conditions; geology, hydrogeology, and surface-water hydrology in the area of the lagoons; local demography; and local and regional land and water use.

2.3.1 Climatology

The UMDA is located in a region characterized by a semi-arid, cold desert climate. The average annual precipitation is 8 to 9 inches, with the majority of that occurring

between November and March. The potential evapotranspiration is high, averaging 32 inches per year. The average temperature at the UMDA is 75° F during the summer and 35° F during the winter. The maximum and minimum temperatures recorded between 1932 and 1985 are 113° F and -31° F respectively (Dames & Moore, 1990a).

Wind data are routinely collected at the Pendleton Municipal Airport, located approximately 30 miles east of the UMDA facility. Mean wind speed is typically 8 to 11 miles per hour; the prevailing weather patterns and strong winds are from the west and southwest (Dames & Moore, 1990a).

2.3.2 Geomorphology and Surface Water Hydrology

The UMDA is located within the Umatilla Basin, a subarea of the Deschutes-Umatilla Plateau. The plateau is an area of relatively low relief in northeastern Oregon. It rises southward from elevations near 260 feet mean sea level (msl) at the Columbia River to approximately 800 feet msl at the foot of the Blue Mountains. The Columbia River is approximately 3 miles north of the northern boundary of UMDA, while the edge of the Blue Mountains lies approximately 40 miles south and southeast of UMDA (Dames & Moore, 1990a).

The Umatilla River, located approximately 1 to 2 miles east of the UMDA, is the primary stream in the Umatilla Basin. The principal tributaries of the Umatilla River rise in the Blue Mountains and flow generally northward to the Columbia River. Butter

Creek is the largest tributary in the area. Parts of the basin are drained by smaller streams that empty directly into the Columbia.

UMDA's natural topography can be divided into three areas—Coyote Coulee, sloping lands east of the coulee, and rolling hills west of the coulee. Coyote Coulee is a valley about 2,500 feet wide that extends north-northeast and south-southwest to the boundaries of the UMDA. The coulee is the major surface drainage feature within the UMDA. A steep escarpment rises to the east of Coyote Coulee; the ground surface slopes southeastward away from the escarpment toward the Umatilla River at a slope of approximately 50 feet per mile (Dames & Moore, 1990a). No natural streams occur within UMDA because of the highly permeable nature of the soils. Drainage patterns are very poorly developed. Many areas of closed drainage exist, particularly west of Coyote Coulee, with the largest about 100 acres in size.

The Explosives Washout Lagoons were constructed at the base of Coyote Coulee, at an elevation of approximately 550 feet msl (Dames & Moore, 1992). The topography of the site is shown in Figure 2-2. From the vicinity of the lagoons, the land surface slopes gently to the southwestward. Surface drainage, as elsewhere at UMDA, is poorly developed. Little runoff is expected to flow into the lagoons from the surrounding area because of the raised berms, and any ponding within the lagoons is expected to infiltrate quickly.

2.3.3 Geology and Hydrogeology

The geology of UMDA has been studied by Dames & Moore (1992) and is characterized by three distinct geological units. From youngest to oldest, these consist of unconsolidated glaciofluvial flood gravels (alluvium), cemented basalt gravel/weathered basalt (CBG/WB) and underlying gravels, and moderately weathered to unweathered basalt. The alluvium is as much as 200 feet thick near UMDA, but ranges from 50 to 154 feet thick in the vicinity of the lagoons, generally representing topographic variation. The glacial flood gravels are exposed at ground surface at the lagoons. The CBG/WB is the uppermost bedrock unit under the site, and ranges from 14 to 28 feet thick, with underlying gravels about 30 to 50 feet thick. The uppermost basalt unit is 89 to 106 feet thick, and has a moderately fractured surface.

Groundwater occurs primarily in two hydrogeologic settings: in a shallow unconfined aquifer and in a vertical sequence of relatively deep basalt aquifers. Dames & Moore (1992) describes the latter as confined aquifers, although there is evidence of hydraulic interconnection with the unconfined aquifer. The unconfined aquifer includes the alluvium, the CBG/WB and its underlying gravels, and possibly the upper weathered portion of the basalt. The basalt aquifers consist primarily of interbeds between unweathered basalt flows.

The depth to groundwater varies seasonally, depending on the availability of recharge and regional irrigation activities. The water table elevation generally ranges between

495 and 500 feet msl over the year (Dames & Moore, 1992), or about 44 to 49 feet below the bottom of the lagoons. The observed depth to groundwater during the November 1991 sampling event was 47 to 48 feet (MKES/CH2M HILL, 1992). The saturated thickness of the unconfined aquifer at the lagoons ranges from approximately 100 to 127 feet (Dames & Moore, 1992.) The CBG/WB appears to be too porous and highly weathered to form an effective confining bed between the alluvium and the basaltic gravels (Dames & Moore, 1992).

The piezometric surface elevation measured in the deep aquifer well closest to the lagoons ranges from 440 to 450 feet msl, or approximately 100 feet below the lagoons. In general, the elevations measured in all four of the wells completed by Dames & Moore in the uppermost basalt ranged from 440 to 470 feet msl, which is 35 to 55 feet lower than water levels in adjacent wells completed in the unconfined aquifer. This implies a large downward gradient across the uppermost basalt flow and the potential for downward leakage (Dames & Moore, 1992). In addition, as discussed in Section 2.4, low levels of explosives have been detected in groundwater samples taken from wells completed in the basalt aquifers (Dames & Moore, 1992). Further evaluations by Dames & Moore (1992), including pumping and chemistry studies, concluded that significant quantities of downward leakage appear to be possible under conditions that might reasonably be supposed to exist in the uppermost basalt.

Groundwater monitoring reports indicate that the regional groundwater flow gradient is predominantly towards the northwest (Dames & Moore, 1991). However, the flow

of the shallow unconfined aquifer in the vicinity of the lagoons is apparently affected by groundwater pumpage during the summer and fall irrigation seasons, because well measurements indicate that the gradient then is towards the south/southeast. During the winter and spring, the gradient was calculated to be towards the north (Dames & Moore, 1990a). The shape of the groundwater contaminant plume within the unconfined aquifer suggests that groundwater pumpage might be controlling the direction of plume migration. The groundwater flow of the uppermost basalt aquifer appears to be consistently towards the northwest, with no seasonal reversal of gradient. There are insufficient data to map a plume for the observed contamination in the basalt aquifer.

2.3.4 Surrounding Land Use and Population

The region surrounding UMDA is used primarily for irrigated agriculture. The land to the immediate south, west, and north of the facility is restricted to "exclusive farmland use" through an easement agreement with UMDA. The chief crops are potatoes, sugar beets, alfalfa, and grains. Dryland farming is widespread in the area, with vast fields of wheat grown in the neighboring uplands. Livestock are raised on the surrounding lands.

The Union Pacific Railroad tracks run adjacent to UMDA's southern boundary. Interstate 84 runs east-west immediately south of the facility, and Interstate 82 runs north-south immediately to the east.

The primary population centers near UMDA include Hermiston (population 10,075), approximately 8 miles east; Umatilla (population 3,032), approximately 6 miles northeast; and Irrigon (population 820), 2 miles northwest. The total populations of Umatilla and Morrow Counties are approximately 59,000 and 7,650, respectively. As of February 1992, 16 military personnel and 32 dependents live on base.

2.3.5 Water Use

A total of 1,468 wells have been identified within the 4-mile radius of UMDA (Dames & Moore, 1990a). Seventy-seven percent (1,126) of the wells are used exclusively for domestic water. Three municipal water systems draw from groundwater within a 4-mile radius of UMDA, including Hermiston, Umatilla and Irrigon. In addition, groundwater serves as the primary source for irrigation. Of the remaining 342 wells that are not used for municipal water supply, more than 161 wells are used for irrigation exclusively (Dames & Moore, 1990a).

Army-owned supply wells on UMDA property include 7 deep wells completed in the basalt aquifers. Water drawn from these wells is used for domestic supply, fire control, industrial uses, and irrigation of landscaped acreage on the installation.

The Columbia River, located 3 miles north of the UMDA boundary, has a flow of approximately 200,000 cubic feet per second. Its level is stabilized near an elevation of

265 feet msl by the John Day Dam. The river is a regional source of potable and irrigation water, and is also used for recreation, fishing, and the generation of hydroelectric power. The principal out-of-stream use of the Umatilla River, located 1 to 2 miles east of UMDA, is irrigation.

The town of Boardman, located on the Columbia River approximately 19 miles downstream from Umatilla, is the only town in the Umatilla Basin that uses surface water exclusively as its municipal water supply.

2.4 Nature and Extent of Contamination

Several soil and groundwater investigations have been conducted in the vicinity of the Explosive Washout Lagoons. The methodology of each of these investigations is summarized in the sections that follow. Conclusions are provided in Section 2.4.5.

Surface and subsurface soil sampling locations are shown in Figure 2-4, and a compilation of soil contamination data is provided in Table 2-1. The locations of monitoring wells installed near the lagoons during these investigations are shown in Figure 2-5. Groundwater monitoring data are presented in Table 2-2.

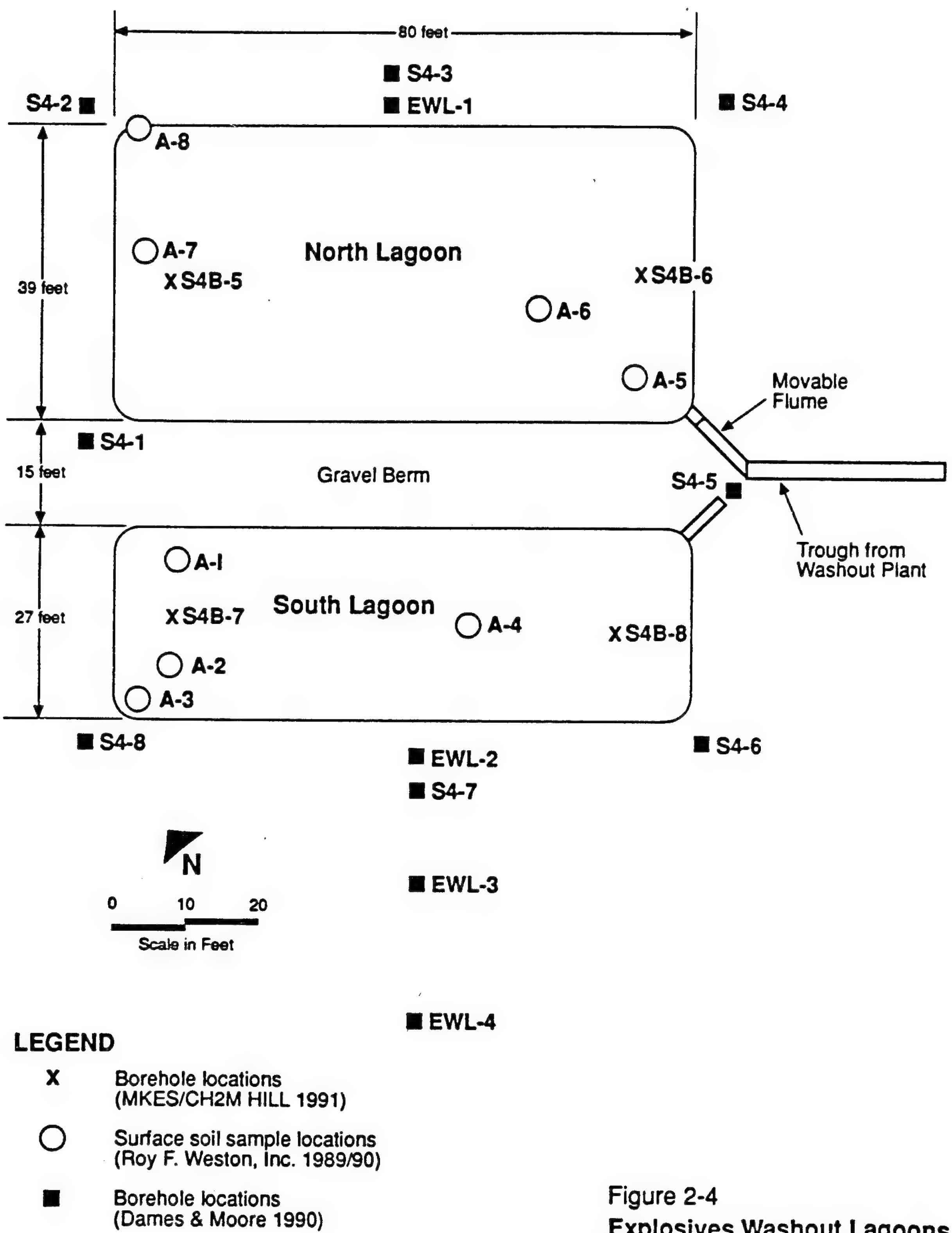


Figure 2-4
Explosives Washout Lagoons Soil Sampling Locations

2.4.1 Battelle Environmental Contamination Survey and Assessment and Century Environmental Services Groundwater Monitoring Report

In 1981, Battelle performed an Environmental Survey and Assessment at UMDA. Activities conducted in the vicinity of the Explosives Washout Lagoons were reviewed by Dames and Moore (1990a) and consisted of the following:

- Nine monitoring wells (numbered 6 through 9 and 21 through 25) were installed in the alluvial aquifer and sampled on four occasions. Groundwater analyses included five explosives (TNT, RDX, tetryl, 2,4-DNT, and 2,6-DNT).

- One surface soil sample was collected from the bottom of each lagoon (S-51 and S-54). Two subsurface samples (S-125 and S-127) were collected at depths of 2.5 and 7.5 feet below the bottom of one of the lagoons. (The sampling locations were not documented and are therefore not shown in Figure 2-4. It is unknown whether the subsurface samples were collected from the north or south lagoon.) Each sample was analyzed for five explosives (TNT, RDX, tetryl, 2,4-DNT, and 2,6-DNT).

Explosives contamination was detected in all four soil samples collected. Only TNT and RDX were detected in the north lagoon surface sample and in the two subsurface

samples. North lagoon surface sample concentrations of TNT and RDX were low to moderate at 38 μg/g and 350 μg/g, respectively. Subsurface concentrations at a depth of 2.5 feet were moderate for both, at 180 μg/g and 260 μg/g, respectively. At a depth of 7.5 feet, concentrations were low at 38 μg/g and 43 μg/g. In the south lagoon, TNT was detected in the surface sample at a high 2,800 μg/g, but RDX was below detection limits. Tetryl, 2,4-DNT, and 2,6-DNT were detected in the south lagoon surface sample, but at low concentrations (4 to 12 μg/g).

The groundwater contaminant concentrations were greatest to the south and east of the lagoons. TNT had the highest concentrations (6,000 to 11,000 μg/l) but was only detected in these concentrations in Well 9 (located to the southeast). Concentrations of TNT were less than 10 μg/l in other wells. Well 9 also had moderately high concentrations of 2,6-DNT (about 700 μg/l). RDX was the most widely distributed groundwater contaminant with concentrations of 100 to 10,000 μg/l in six of the nine wells. 2,4-DNT and tetryl were rarely detected and only in low concentrations (less than 5 μg/l).

Based on the data collected, Battelle concluded that the Explosives Washout Lagoons were a major concern with respect to explosives contamination (Dames & Moore, 1992).

Table 2-1
Explosives Washout Lagoons
Summary of Soil Analytical Results (µg/g)

Site ID	Date	(Ref.)	Depth (a)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
S4B-5	Nov-1991	(MK/CH)	0-2	2.51	<0.496	3.62	<0.424	<0.524	<0.666	200	<2.41	<0.731
			2-3.5	8.59	<0.496	1.47	<0.424	<0.524	1.61	110	<2.41	<0.731
			4-5.5	9.88	<0.496	<0.456	<0.424	<0.524	<0.666	6.01	<2.41	<0.731
			6-7.5	12.9	<0.496	<0.456	<0.424	<0.524	<0.666	11.3	<2.41	<0.731
			8-9.5	29	<0.496	3.02	0.916	<0.524	2.29	16.7	4.3	<0.731
			10-11.5	34	<0.496	8.84	4.45	<0.524	<0.666	19.2	<2.41	<0.731
			15-16.5	40	<0.496	12	4.14	<0.524	30.3	22	<2.41	<0.731
			20-21.5	36	0.747	9.88	<0.424	<0.524	19.4	21.3	<2.41	<0.731
			25-26.5	34	<0.496	12.9	<0.424	<0.524	25.4	33	<2.41	<0.731
			30-31.5	24	<0.496	5.63	<0.424	<0.524	13.6	18.3	<2.41	<0.731
			30-31.5	26.1	<0.496	7.05	2.4	<0.524	13.9	20.3	<2.41	<0.731
			35-36.5	33	0.628	11.5	<0.424	5.56	<0.666	31	<2.41	<0.731
			40-41.5	30	<0.496	15	<0.424	3.81	<0.666	33	<2.41	<0.731
			45-46.5	14.8	<0.496	24	<0.424	2.45	<0.666	3.52	<2.41	<0.731
			50-51.5	8	<0.496	10.1	<0.424	0.872	<0.666	2.73	<2.41	<0.731
S4B-6	Nov-1991	(MK/CH)	0-2	23.6	<0.496	520	<0.424	<0.524	47	1400	<2.41	<0.731
			2-3.5	23	<0.496	780	<0.424	<0.524	27	1500	<2.41	<0.731
			2-3.5	27	<0.496	980	<0.424	<0.524	32.5	1900	<2.41	<0.731
			4-5.5	22.1	<0.496	1.11	<0.424	<0.524	3.64	150	<2.41	<0.731
			6-7.5	39	<0.496	<0.456	0.726	0.708	<0.666	14.2	<2.41	<0.731
			8-9.5	20.7	<0.496	<0.456	<0.424	0.686	2.33	8.48	<2.41	<0.731
			10-11.5	18.8	<0.496	<0.456	<0.424	<0.524	<0.666	4.76	<2.41	<0.731
			15-16.5	27	<0.496	14.1	<0.424	1.31	3.03	10.1	<2.41	<0.731
			20-21.5	26	<0.496	6.56	<0.424	1.53	9.35	13.5	<2.41	<0.731
			25-26.5	7.73	<0.496	6.97	<0.424	<0.524	5.82	6.55	<2.41	<0.731

Table 2-1
Explosives Washout Lagoons
Summary of Soil Analytical Results (µg/g)

Site ID	Date	(Ref.)	Depth (ft)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
S4B-6 (con't)	Nov-1991	(MK/CH)	30-31.5	9.3	<0.496	7.63	0.764	<0.524	7.12	9	<2.41	<0.731
			35-36.5	30	<0.496	8.62	1.49	<0.524	13.2	23.1	<2.41	<0.731
			40-41.5	32	<0.496	13.2	2.62	<0.524	15.6	31	<2.41	<0.731
			45-46.5	14.7	<0.496	14.1	1.7	<0.524	10.2	6.06	<2.41	<0.731
			50-51.5	18	<0.496	27	2.47	<0.524	19	5.15	<2.41	<0.731
S4B-7	Nov-1991	(MK/CH)	0-2	17	<0.496	1400	<0.424	<0.524	<0.666	3.38	<2.41	<0.731
			2-3.5	21	<0.496	1300	<0.424	<0.524	3.35	12.6	<2.41	<0.731
			4-5.5	18	<0.496	0.796	<0.424	<0.524	<0.666	59	<2.41	<0.731
			6-7.5	47	<0.496	1.04	0.683	<0.524	<0.666	36	<2.41	<0.731
			8-9.5	23	<0.496	1.41	0.614	<0.524	<0.666	2.78	<2.41	<0.731
			10-11.5	39	<0.496	4.23	2.65	<0.524	11.4	28	<2.41	<0.731
			15-16.5	39	<0.496	34	16.2	<0.524	47	80	<2.41	<0.731
			20-21.5	1.87	<0.496	4.36	3.04	<0.524	5.13	93	<2.41	<0.731
			25-26.5	22.9	<0.496	11.4	2.93	<0.524	16.4	30	<2.41	<0.731
			30-31.5	40	<0.496	20.2	3.96	<0.524	21.9	65	<2.41	<0.731
			35-36.5	20.9	<0.496	2.16	1.21	<0.524	3.67	9.68	<2.41	<0.731
			40-41.5	38	0.999	4.57	2.34	<0.524	7.93	12.6	<2.41	<0.731
			45-46.5	18	<0.496	24	3.47	<0.524	13	2.91	<2.41	<0.731
			45-46.5	19	0.547	27	4.41	<0.524	14.8	3.24	<2.41	<0.731
S4B-8	Nov-1991	(MK/CH)	0-2	20	<0.496	740	<0.424	<0.524	9.83	13.4	<2.41	<0.731
			2-3.5	8.35	<0.496	13.9	<0.424	<0.524	<0.666	1.73	<2.41	<0.731
			4-5.5	13.7	<0.496	19.7	<0.424	<0.524	<0.666	<0.587	<2.41	<0.731
			6-7.5	15.3	<0.496	1.99	<0.424	<0.524	<0.666	1.67	<2.41	<0.731
			8-9.5	9.29	<0.496	0.612	<0.424	<0.524	<0.666	<0.587	<2.41	<0.731
			10-11.5	13	<0.496	8.03	2.18	<0.524	1.6	2.13	<2.41	<0.731

Table 2-1
Explosives Washout Lagoons
Summary of Soil Analytical Results (µg/g)

Site ID	Date	(Ref.)	Depth (ft)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
S4B-8 (con't)	Nov-1991	(MK/CH)	15-16.5	17.8	<0.496	7.17	2.51	<0.524	1.84	10.9	<2.41	<0.731
			15-16.5	17.9	<0.496	7.85	2.54	<0.524	2.05	11.1	<2.41	<0.731
			20-21.5	27	<0.496	11.4	4.3	<0.524	2.84	15.2	<2.41	<0.731
			25-26.5	40	<0.496	25	6.9	<0.524	6.6	29	<2.41	<0.731
			30-31.5	21.7	<0.496	7.68	2.62	<0.524	2.20	7.26	<2.41	<0.731
			35-36.5	40	<0.496	29	3.75	<0.524	6.04	11.4	<2.41	<0.731
			40-41.5	35	<0.496	38	4.41	<0.524	9.37	23.1	<2.41	<0.731
			45-46.5	36	<0.496	19.7	3.37	<0.524	15.6	3.91	<2.41	<0.731
			50-51.5	19	<0.496	15.1	2.29	<0.524	7.93	<0.587	<2.41	<0.731
S4-1	29-June-1990	(D&M)	0	32.00	<0.50	340.00	<0.42	<0.52	27.20	660.00	<2.41	<0.73
			2	25.00	<0.50	58.00	0.55	<0.52	13.10	120.00	27.10	<0.73
			4	1.09	<0.50	1.89	<0.42	<0.52	2.09	19.30	<2.41	<0.73
			6	18.00	0.85	1.78	<0.42	<0.52	15.60	30.00	3.90	<0.73
			8	45.00	0.84	1.04	<0.42	<0.52	10.90	7.87	<2.41	<0.73
S4-2	26-June-1990	(D&M)	0	2.19	<0.50	1.07	<0.42	<0.52	4.04	37.00	<2.41	<0.73
			2	<0.49	<0.50	<0.46	<0.42	<0.52	3.04	11.40	<2.41	<0.73
			4	<0.49	<0.50	<0.46	<0.42	<0.52	1.59	3.75	<2.41	<0.73
			6	<0.49	<0.50	<0.46	<0.42	<0.52	0.86	3.40	<2.41	<0.73
			8	<0.49	<0.50	<0.46	<0.42	<0.52	<0.67	3.10	<2.41	<0.73
S4-3	26-June-1990	(D&M)	0	<0.49	<0.50	<0.46	<0.42	<0.52	4.70	13.00	<2.41	<0.73
			2	<0.49	<0.50	<0.46	<0.42	<0.52	5.09	16.70	<2.41	<0.73
			4	<0.49	<0.50	<0.46	<0.42	<0.52	1.85	5.51	<2.41	<0.73
			6	<0.49	<0.50	<0.46	<0.42	<0.52	2.25	6.80	<2.41	<0.73
			8	<0.49	<0.50	<0.46	<0.42	<0.52	1.55	5.22	<2.41	<0.73

Table 2-1
Explosives Washout Lagoons
Summary of Soil Analytical Results (μg/g)

Site ID	Date	(Ref.)	Depth (a)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
S4-4	26-June-1990	(D&M)	0	1.06	<0.50	3.69	<0.42	<0.52	21.90	110.00	<2.41	<0.73
			2	<0.49	<0.50	2.65	<0.42	<0.52	7.95	31.00	<2.41	<0.73
			4	<0.49	<0.50	0.72	<0.42	<0.52	6.37	30.00	<2.41	<0.73
			6	<0.49	<0.50	<0.46	<0.42	<0.52	0.72	6.50	<2.41	<0.73
			8	<0.49	<0.50	<0.46	<0.42	<0.52	<0.67	2.60	<2.41	<0.73
S4-4 Dup.	26-June-1990	(D&M)	8	<0.49	<0.50	<0.46	<0.42	<0.52	<0.67	3.05	<2.41	<0.73
S4-5	28-June-1990	(D&M)	0	29.00	<0.50	3400.00	12.00	<5.20	68.00	450.00	<2.41	<0.73
			2	47.00	<0.50	5500.00	<21.00	<26.00	81.00	420.00	<2.41	<0.73
			4	31.00	0.55	3800.00	<21.00	<26.00	47.00	220.00	<2.41	<0.73
			6	16.90	<0.50	1100.00	<21.00	<26.00	15.00	66.00	<2.41	<0.73
			8	9.19	<0.50	1.83	0.51	<0.52	1.23	22.40	<2.41	<0.73
S4-6	28-June-1990	(D&M)	0	<0.49	<0.50	0.87	<0.42	<0.52	1.39	0.73	<2.41	<0.73
			2	<0.49	<0.50	<0.46	<0.42	<0.52	0.69	<0.59	<2.41	<0.73
			4	<0.49	<0.50	<0.46	<0.42	<0.52	0.72	<0.59	<2.41	<0.73
			6	<0.49	<0.50	<0.46	<0.42	<0.52	0.73	<0.59	<2.41	<0.73
			8	<0.49	<0.50	<0.46	<0.42	<0.52	1.33	0.91	<2.41	<0.73
			20	<0.49	<0.50	0.78	<0.42	<0.52	<0.67	8.53	<2.41	<0.73
			30	<0.49	<0.50	0.61	<0.42	<0.52	<0.67	22.30	<2.41	<0.73
			40	17.00	<0.50	8.59	1.05	<0.52	7.04	11.20	<2.41	<0.73
			50	22.50	<0.50	17.80	2.06	<0.52	13.40	3.61	<2.41	<0.73
S4-7	28-June-1990	(D&M)	0	<0.49	<0.50	<0.46	<0.42	<0.52	<0.67	<0.59	<2.41	<0.73
			2	<0.49	<0.50	<0.46	<0.42	<0.52	<0.67	<0.59	<2.41	<0.73
			4	<0.49	<0.50	<0.46	<0.42	<0.52	0.98	<0.59	<2.41	<0.73
			6	0.93	<0.50	<0.46	<0.42	<0.52	0.94	<0.59	<2.41	<0.73
			8	0.99	<0.50	<0.46	<0.42	<0.52	1.21	<0.59	<2.41	<0.73

Table 2-1
Explosives Washout Lagoons
Summary of Soil Analytical Results ($\mu g/g$)

Site ID	Date	(Ref.)	Depth (ft)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
S4-7 Dup.	28-June-1990	(D&M)	6	0.97	<0.50	<0.46	<0.42	<0.52	<0.67	0.70	<2.41	<0.73
S4-8	29-June-1990	(D&M)	0	3.99	<0.50	53.00	<0.42	<0.52	11.30	100.00	<2.41	<0.73
			2	<0.49	<0.50	0.82	<0.42	<0.52	1.27	4.55	<2.41	<0.73
			4	<0.49	<0.50	<0.46	<0.42	<0.52	0.81	3.02	<2.51	<0.73
			6	<0.49	<0.50	<0.46	<0.42	<0.52	<0.67	1.83	<2.41	<0.73
			8	<0.49	<0.50	<0.46	<0.42	<0.52	.071	2.04	<2.41	<0.73
			20	<0.49	<0.50	<0.46	<0.42	<0.52	<0.67	9.12	<2.41	<0.73
			30	<0.49	<0.50	<0.46	<0.42	<0.52	<0.67	18.70	<2.41	<0.73
			40	11.40	<0.50	8.38	1.10	<0.52	4.99	26.00	<2.41	<0.73
			50	11.40	<0.50	12.50	1.74	<0.52	5.97	2.23	<2.41	<0.73
A-1	05-Oct-1989	(WES)	0-1"	--	--	45582	--	--	<127.0	<98	--	--
A-2	05-Oct-1989	(WES)	0-6"	--	--	618	--	--	0.7	2.13	--	--
A-3	05-Oct-1989	(WES)	0-1"	--	--	87623	--	--	483	731	--	--
A-4	05-Oct-1989	(WES)	0"	--	--	318	--	--	0.56	<0.98	--	--
A-5	05-Oct-1989	(WES)	0-6"	--	--	14.3	--	--	15.4	5.1	--	--
A-6	05-Oct-1989	(WES)	9-10"	--	--	<1.92	--	--	2.26	204	--	--
A-7	05-Oct-1989	(WES)	0-6"	--	--	1618	--	--	57.6	246	--	--
A-8	05-Oct-1989	(WES)	0-1"	--	--	4.43	--	--	<1.27	0.82	--	
EWL-1	27-Apr-1988	(WES)	3.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	3.80	<0.42	<0.25
			5.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<2.10	<0.42	<0.25
			7.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	2.30	<0.42	<0.25
			10.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			20.3	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	2.00	<0.42	<0.25
			30.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	1.60	<0.42	<0.25
			40.7	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25

Table 2-1
Explosives Washout Lagoons
Summary of Soil Analytical Results ($\mu g/g$)

Site ID	Date	(Ref.)	Depth (a)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
EWL-1 (con't)			50.2	<2.09	<0.59	0.54	0.52	<0.40	3.00	3.00	<0.42	<0.25
EWL-2	26-Apr-1988	(WES)	3.1	3.20	<0.59	4.40	0.56	<0.40	1.30	3.20	<0.42	<0.25
			5.1	2.10	<0.59	<1.92	<0.42	<0.40	<1.27	2.10	<0.42	<0.25
			7.1	<0.98	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			10.1	1.10	<0.59	<1.92	<0.42	<0.40	<1.27	1.10	<0.42	<0.25
			20.3	7.90	<0.59	<1.92	0.57	<0.40	3.40	7.90	<0.42	<0.25
			30.1	6.80	<0.59	13.00	0.89	<0.40	3.50	6.90	<0.42	<0.25
			40.7	10.00	<0.59	11.00	0.73	<0.40	4.40	10.00	<0.42	<0.25
EWL-3	27-Apr-1988	(WES)	3.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			5.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			7.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			10.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			20.3	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			30.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			40.7	12.00	<0.59	5.80	1.80	<0.40	19.00	5.30	<0.42	<0.25
EWL-4	27-Apr-1988	(WES)	3.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			5.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			7.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			10.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			20.3	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			30.1	<2.09	<0.59	<1.92	<0.42	<0.40	<1.27	<0.98	<0.42	<0.25
			40.7	4.90	<0.59	4.40	0.99	<0.40	7.50	6.80	<0.42	<0.25
			50.2	<2.09	<0.59	4.40	0.57	<0.40	<1.27	<0.98	<0.42	<0.25

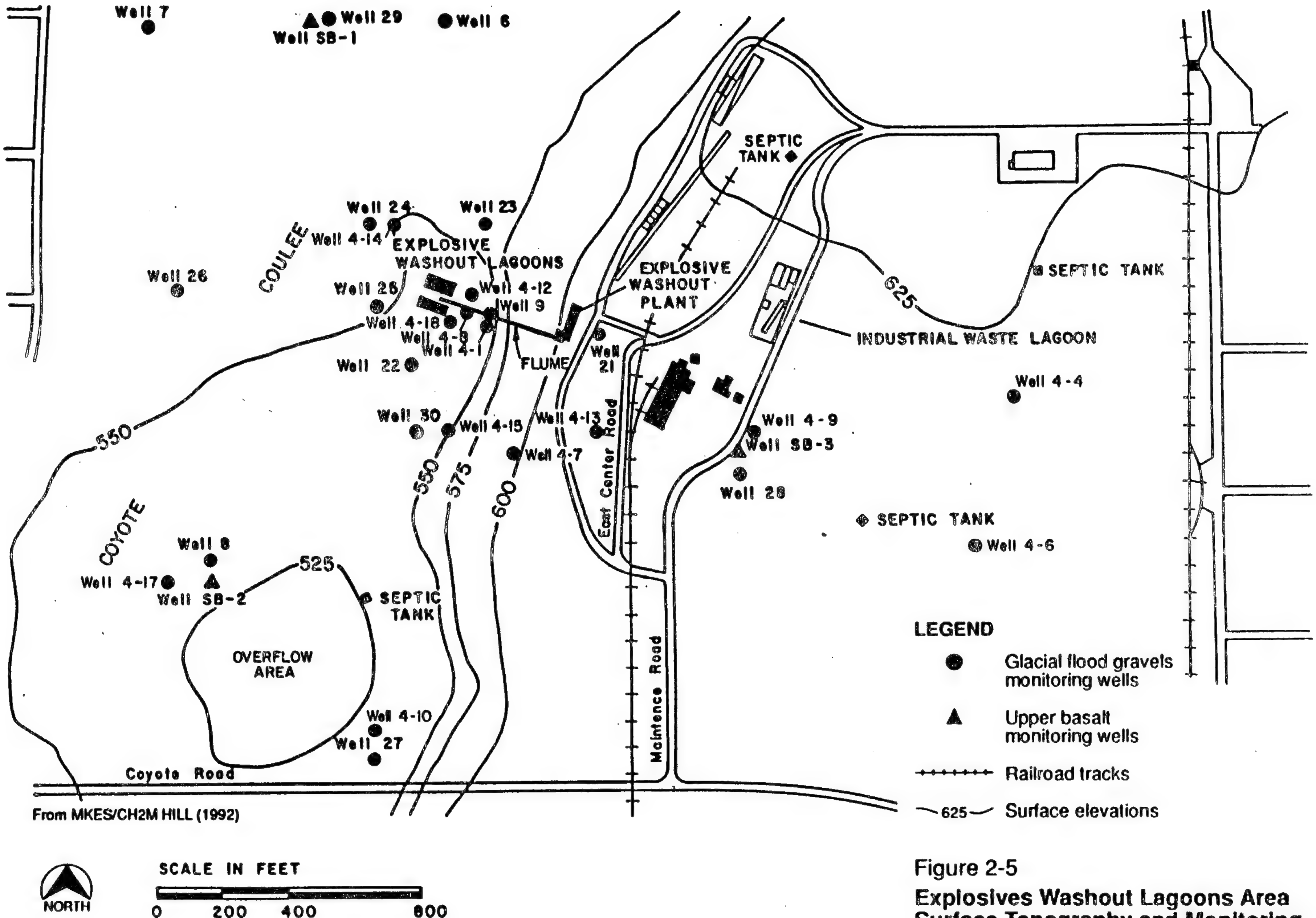
Table 2-1
Explosives Washout Lagoons
Summary of Soil Analytical Results ($\mu g/g$)

Site ID	Date	(Ref.)	Depth (a)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
South Lagoon; S-54	09-Mar-1981	(BAT)	0"	NA	NA	38	<0.41	<0.39	NA	350	NA	<0.75
North Lagoon; S-51	09-Mar-1981	(BAT)	0"	NA	NA	2800	4.3	5.4	NA	<8.9	NA	12
S-125	23-Mar-1981	(BAT)	2.5	NA	NA	180	<0.41	<0.39	NA	260	NA	<0.75
S-127	23-Mar-1981	(BAT)	7.5	NA	NA	38	<0.41	<0.39	NA	43	NA	<0.75

(a)=Depth in feet except where otherwise indicated.
BAT=Data collected by Battelle and summarized in Dames & Moore (1991).
MK/CH=From MKES/CH2M HILL (1992).
D&M=From Dames & Moore (1991).
WES=Data collected by Weston and summarized in Dames & Moore (1991).
NA=Not analyzed.

Data detected at concentrations greater than the detection limit are highlighted by shading for easy observation.

10020D2B.SEA



From MKES/CH2M HILL (1992)

Figure 2-5
Explosives Washout Lagoons Area Surface Topography and Monitoring Well Locations

Table 2-2
Explosives Washout Lagoons
Summary of Groundwater Analytical Results (µg/l)

Well ID	Depth	Date	(Ref.)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
6	Alluvial	23-Apr-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
		15-Jul-1981	(BAT)	NA	NA	3.3	<0.48	0.70	NA	<7.4	NA	<0.98
		04-Nov-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
		07-Mar-1986	(CES)	NA	NA	<1	<1	<1	<100	<30	NA	<10
		15-Aug-1986	(CES)	NA	NA	<1	<1	<1	<100	<30	NA	<10
		26-Feb-1987	(CES)	NA	NA	<1	<1	<1	<100	<30	NA	<10
		13-Aug-1987	(CES	NA	NA	<1	<1	<1	<100	<30	NA	<10
		21-June-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	4.37	<1.13	<0.66
		07-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
		27-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
7	Alluvial	22-Apr-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
		15-Jul-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
		04-Nov-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
		07-Mar-1986	(CES)	NA	NA	<1	<1	<1	<100	<30	NA	<10
		15-Aug-1986	(CES)	NA	NA	<1	<1	<1	<100	<30	NA	<10
		26-Feb-1986	(CES)	NA	NA	<1	<1	<1	<100	<30	NA	<10
		13-Aug-1987	(CES)	NA	NA	<1	<1	<1	<100	<30	NA	<10
		21-Jun-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	<0.63	<1.13	<0.66
		06-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
		28-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
8	Alluvial	21-Apr-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
		16-Jul-1981	(BAT)	NA	NA	NA	NA	NA	NA	NA	NA	NA
		04-Nov-1981	(BAT)	NA	NA	0.73	<0.48	<0.43	NA	<7.4	NA	<0.98
		07-Mar-1986	(CES)	NA	NA	<1	1.6	<1	<100	<30	NA	<10
		15-Aug-1986	(CE)	NA	NA	6.8	1.4	<1	297	<30	NA	<10
		27-Feb-1987	(CES)	NA	NA	<1	<1	<1	<100	<30	NA	<10
		14-Aug-1987	(CES)	NA	NA	<1	<1	<1	<100	85	NA	<10

Table 2-2
Explosives Washout Lagoons
Summary of Groundwater Analytical Results (µg/l)

Well ID	Depth	Date	(Ref.)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
8 (cont.)		17-Jun-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	66.0	<1.13	<0.66
		08-Nov-1990	(D&M)	<0.63	<0.52	0.90	<0.61	<1.15	<1.65	3.04	<1.07	<0.56
		18-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	17.4	<1.07	<0.56
9	Alluvial	22-Apr-1981	(BAT)	NA	NA	11,000	<0.48	760	NA	10,000	NA	<0.98
		15-Jul-1981	(BAT)	NA	NA	8,800	4.5	600	NA	1,800	NA	0.98
		04-Nov-1981	(BAT)	NA	NA	6,100	3.8	390	NA	1,500	NA	0.98
		07-Mar-1986	(CES)	NA	NA	4,350	400	5.1	1,300	7,400	NA	<10
		15-Aug-1986	(CES)	NA	NA	3,950	36.5	<1	2,530	6,125	NA	<10
		27-Feb-1987	(CES)	NA	NA	3,700	<1	<1	2,000	6,900	NA	<10
		14-Aug-1987	(CES)	NA	NA	3,110	<1	<1	1,680	7,430	NA	<10
		07-Jul-1988	(WES)	420	<0.61	3,400	330	5.30	1,400	3,700	<1.13	<0.66
		08-Nov-1990	(D&M)	420	17.9	3,100	340	<1.15	390	2,800	15.7	<0.56
		19-Feb-1991	(D&M)	441	8.82	3,158	431	<1.15	1,288	3,643	<1.07	<0.56
21	Alluvial	05-Nov-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	1,500	NA	<0.98
		08-Jul-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	9.89	2,900	<1.13	<0.66
		13-Nov-1990	(D&M)	1.98	<0.52	<0.59	<0.61	<1.15	31.9	2,200	<1.07	<0.56
		05-Mar-1991	(D&M)	1.89	<0.52	<0.59	<0.61	<1.15	32.2	2,468	<1.07	<0.56
22	Alluvial	04-Nov-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	960	NA	<0.98
		07-Jul-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	1.91	0.68	<1.13	<0.66
		07-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	54	<1.07	<0.56
		19-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	123	<1.07	<0.56
23	Alluvial	04-Nov-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	140	NA	<0.98
		07-Jul-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	230	<1.13	<0.66
		08-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	260	<1.07	<0.56
		19-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	200	<1.07	<0.56

Table 2-2
Explosives Washout Lagoons
Summary of Groundwater Analytical Results (µg/l)

Well ID	Depth	Date	(Ref.)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
24	Alluvial	05-Nov-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	270	NA	<0.98
		07-Jul-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	100	<1.13	<0.66
		15-Nov-1990	(D&M)	0.79	<0.52	<0.59	<0.61	<1.15	<1.65	200	<1.07	<0.56
		26-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	347	<1.07	<0.56
25	Alluvial	04-Nov-1981	(BAT)	NA	NA	<0.47	<0.48	<0.43	NA	310	NA	<0.98
		07-Jul-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	560	<1.13	<0.66
		08-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	220	<1.07	<0.56
		28-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	176	<1.07	<0.56
26	Alluvial	21-Jun-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	<0.63	<1.13	<0.66
		02-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
		13-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
27	Alluvial	22-Jun-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	83	<1.13	<0.66
		05-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	3.49	<1.07	<0.56
		26-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	6.52	<1.07	<0.56
28	Alluvial	17-Jun-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	1,000	<1.13	<0.66
		05-Nov-1990	(D&M)	2.40	1.57	<0.59	<0.61	<1.15	15.6	5,000	<1.07	<0.56
		14-Feb-1991	(D&M)	3.37	0.64	<0.59	<0.61	<1.15	17.4	2,115	<1.07	<0.56
29	Alluvial	17-Jun-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	<0.63	<1.13	<0.66
		06-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
		15-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
30	Alluvial	21-Jun-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	0.91	<1.13	<0.66
		05-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
		14-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
SB-1	Sh.Basalt	20-Jun-1988	(WES)	<0.56	<0.61	2.91	<0.60	<0.55	<1.30	<0.63	<1.13	<0.66
		02-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	4.81	<1.07	<0.56
		13-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56

Table 2-2
Explosives Washout Lagoons
Summary of Groundwater Analytical Results (µg/l)

Well ID	Depth	Date	(Ref.)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
SB-2	Sh.Basalt	17-Jun-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	2.16	<1.13	<0.66
		04-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	76	<1.07	<0.56
		19-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	3.97	10.1	<1.07	<0.56
SB-3	Sh.Basalt	16-Jun-1988	(WES)	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	0.65	<1.13	<0.66
		04-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	8.26	<1.07	<0.56
		19-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	5.32	<1.07	<0.56
4-1	Flood Gravel	06-Nov-1990	(D&M)	320	15.7	3,400	340	<1.15	1,300	2,700	13.1	<0.56
		19-Feb-1991	(D&M)	441	1.92	2,573	371	<1.15	1,288	2,585	<1.07	<0.56
4-2	Flood Gravel	05-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
		19-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-3	Flood Gravel	04-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	120	<1.07	<0.56
		19-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	112	<1.07	<0.56
4-4	Flood Gravel	04-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	36.2	<1.07	<0.56
		18-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	45.9	<1.07	<0.56
4-5	Flood Gravel	02-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	590	<1.07	<0.56
		20-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	1.93	523	<1.07	<0.56
4-6	Flood Gravel	02-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	270	<1.07	<0.56
		26-Feb-1991	(D&M)	<0.63	<0.52	0.89	<0.61	<1.15	<1.65	411	<1.07	<0.56
4-7	Flood Gravel	04-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	510	<1.07	<0.56
		20-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	558	<1.07	<0.56
4-8	Basalt	16-Oct-1990	(D&M)	<0.63	<0.52	0.83	1.49	<1.15	10.8	44.8	<1.07	<0.56
		28-Feb-1991	(D&M)	39.2	0.85	392	59.9	<1.15	349	646	<1.07	<0.56
4-9	Basalt	21-Oct-1990	(D&M)	<0.63	<0.52	1.67	<0.61	<1.15	1.86	1,100	<1.07	<0.56
		01-Mar-1991	(D&M)	0.78	1.01	<0.59	<0.61	<1.15	8.31	5,640	<1.07	<0.56
4-10	Basalt	16-Oct-1990	(D&M)	1.32	<0.52	0.95	<0.61	<1.15	<1.65	27.4	<1.07	<0.56
		27-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	1.86	1.29	<1.07	<0.56

Table 2-2
Explosives Washout Lagoons
Summary of Groundwater Analytical Results (μg/l)

Well ID	Depth	Date	(Ref.)	135TNB	13DNB	246TNT	24DNT	26DNT	HMX	RDX	NB	TETRYL
4-12	Flood Gravel	06-Nov-1990	(D&M)	<0.63	<0.52	1.51	<0.61	<1.15	<1.65	6.6	<1.07	<0.56
		20-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-13	Flood Gravel	05-Nov-1990	(D&M)	<0.63	<0.52	0.75	0.79	<1.15	9.33	2,400	<1.07	0.76
		20-Feb-1991	(D&M)	<0.63	1.04	<0.59	0.77	<1.15	11.16	2,115	<1.07	<0.56
4-14	Flood Gravel	02-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	2.74	<1.07	<0.56
		26-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-15	Flood Gravel	05-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
		20-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-16	Flood Gravel	02-Nov-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
		28-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-17	Basalt	16-Oct-1990	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	3.33	16.8	<1.07	<0.56
		28-Feb-1991	(D&M)	<0.63	<0.52	<0.59	<0.61	<1.15	2.72	98.7	<1.07	<0.56
4-18	Flood Gravel	05-Nov-1990	(D&M)	270	7.84	3,900	430	<1.15	1,400	1,800	15.8	<0.56
		27-Feb-1991	(D&M)	257	2.51	3,626	497	<1.15	1,449	2,056	<1.07	<0.56

BAT=Data collected by Battelle and summarized in Dames & Moore (1991).
CES=Data collected by Century Environmental Services and summarized in Dames & Moore (1991).
WES=Data collected by Roy F. Weston, Inc. and summarized in Dames & Moore (1991).
D&M=From Dames & Moore (1991).
NA=Not analyzed.

Data detected at concentrations greater than the detection limit are highlighted by shading for easy observation.

In 1986 and 1987, Century Environmental Services used four of the existing Battelle wells (Wells 6 through 9) to sample and analyze groundwater, adding an analysis for HMX. The observed data trends were consistent with the Battelle study, except that Well 9 concentrations of 2,4-DNT had increased to 400 μg/l and 2,6-DNT concentrations had dropped to 5 μg/l. In addition, concentrations of TNT in Well 9 were somewhat lower (3,100 to 4,000 μg/l) than in the Battelle study. HMX was found in high (>1,000 μg/l) concentrations in Well 9.

2.4.2 Roy F. Weston, Inc., Investigations

From 1988 through 1990, Roy F.Weston, Inc. (Weston) conducted field investigations at the Explosives Washout Lagoons, summarized by Dames & Moore (1990a). Samples were analyzed for a suite of nine explosives: TNT, RDX, HMX, tetryl, 2,4-DNT, 2,6-DNT, TNB, DNB, and NB. Activities conducted in 1988 included the following:

- Five new monitoring wells (numbers 26 through 30) were installed in the alluvial aquifer and three wells in what was interpreted as shallow basalt bedrock (SB-1 through SB-3). These plus the previous nine wells installed by Battelle were sampled.

- Subsurface soil samples were collected at intervals from 2 to 5 feet deep to approximately 50 feet deep (top of saturated alluvium) from borings

completed in four locations (EWL-1 through EWL-4) on the northeast and southwest sides of the lagoons.

- Composite surface soil samples were collected from the overflow area southwest of the washout plant.

- Short-term aquifer tests were conducted in two of the alluvial monitoring wells.

Results from the alluvial aquifer sampling were consistent with previous studies. Again, Well 9 was the most contaminated well, with high concentrations of TNT (3,400 μg/l), RDX (5,700 μg/l), HMX (1,400 μg/l), TNB (420 μg/l), and 2,4-DNT (330 μg/l). RDX was also detected, usually in moderate-to-high concentrations (100 to 300 μg/l), in 10 of the remaining 13 alluvial wells. The RDX plume appeared to extend primarily to the southeast and southwest. HMX, the only other explosive detected in the remaining wells, was found in 2 of the 13 wells. The shallow basalt aquifer was found to contain low (less than 10 μg/l) but detectable levels of RDX and TNT.

From water level measurements, Weston inferred that the alluvial aquifer and the shallow basalt aquifer are hydraulically connected. The alluvial aquifer had a slight gradient towards the south/southeast during the summer and fall, which reversed towards the north during the winter and spring.

Five of the nine explosives (TNT, RDX, HMX, TNB, and 2,4-DNT) were detected in the soil samples collected from the borings adjacent to the lagoons. All concentrations were less than 20 μg/g. In the two borings located 10 feet from the lagoons in the northern and southern berms (EWL-1 and EWL-2), one or more contaminants were detected at every depth interval. Contaminant detections and concentrations increased at the saturated interface. In the borings located 50 feet and 100 feet south of the lagoons (EWL-3 and EWL-4), contaminants were only detected at the saturated interface (40 to 50 feet below grade).

In 1989, Weston collected eight additional soil samples (numbered A-1 through A-8) from the interior of the lagoons. Sampling depths ranged from the soil surface to 10 inches below the surface, and samples were only analyzed for TNT, RDX, and HMX. Concentrations of TNT exceeded 1,000 μg/g in three locations, with a maximum of 87,623 μg/g. The remaining samples contained TNT, RDX, and HMX at concentrations ranging from below detection to 800 μg/g (Dames & Moore, 1990a).

2.4.3 Dames & Moore Remedial Investigation

In 1990 and 1991, Dames & Moore (1992) conducted an installation-wide remedial investigation (RI) that included the Explosives Washout Lagoons. Field activities included the following:

- Samples were collected from borings completed at eight locations (S4-1 through S4-8) in the berms, 15 to 20 feet from the lagoons. Two of these (S4-6 and S4-8, on the south and west corners) were completed to a depth of 50 feet, while the remainder were completed to 10 feet. The samples were analyzed for nitrate/nitrite and nine explosives (TNT, RDX, HMX, tetryl, 2,4-DNT, 2,6-DNT, TNB, DNB, and NB).

- Seventeen new wells were installed, 13 in the unconfined alluvial aquifer and four in the uppermost basalt aquifer. Groundwater samples from these plus the 17 existing wells were analyzed for nitrate/nitrite and the same nine explosives.

The following soil sampling results are summarized from the data compiled in Dames & Moore (1991). In reviewing the results, it is important to note that a depth of 6 feet in the berms is approximately coincident with the bottom elevation of the lagoons.

- The two borings completed at either end of the berm dividing the lagoons exhibited the highest overall explosives concentrations. Boring S4-1 at the north end of the central berm (farthest from the flume) exhibited RDX concentrations of 30 to 660 µg/g to a depth of 6 feet, and TNT concentrations of 58 to 340 µg/g to a depth of 2 feet. Boring S4-5 at the south end of the central berm (immediately under the movable flume) exhibited RDX concentrations of 66 to 450 µg/g to a depth of

6 feet, and TNT concentrations of 1,100 to 5,500 μg/g to a depth of 6 feet. At each location, concentrations below 6 feet were less than 30 μg/g.

- The surface sample collected from S4-8 showed a TNT concentration of 53 μg/g and RDX concentration of 100 μg/g. In all remaining samples, TNT and RDX concentrations were below 30 μg/g. Other explosives found in the soils were generally at low concentrations and limited to a few samples.

- In the two borings completed to 50 feet, there is a consistent pattern of a greater number of contaminant detections and higher concentrations in the upper 2 feet, followed by decreased detections and concentrations from a depth of 2 feet to about 30 to 40 feet, then an increase in detections and concentrations from 30 feet to the water table.

Based on the observed elevation of concentrations of explosives in subsurface soils at the saturated/unsaturated interface (as observed in this study and the Weston study), Dames & Moore suggested that groundwater contamination might contribute to soil contamination.

The groundwater data collected by Dames & Moore were generally consistent with earlier investigations.

- Wells 9, 4-1, and 4-18 exhibited the highest degree of contamination. RDX concentrations in these wells ranged from 1,800 to 3,600 μg/l; TNT concentrations from 2,600 to 3,900 μg/l; HMX concentrations from 600 to 1,400 μg/l; 2,4-DNT concentrations from 340 to 500 μg/l; and 1,3,5-TNB concentrations from 260 to 440 μg/l. Other contaminants were rarely detected, and the only contaminant with a significant presence in other wells was RDX.

- RDX was the most widely detected contaminant, found in 28 of the 34 wells. Based on its presence in well 4-3, RDX has potentially traveled at least 2,000 feet from the lagoons. Although the alluvial plume was not well-defined, high (1,000 to 13,000 μg/l) concentrations in wells 9, 21, 28, 4-1, 4-13, and 4-18, and the absence of RDX in wells to the northwest (7, 26, 29, and 4-2) suggest that groundwater transport occurs primarily to the south.

- All three of the wells completed in the deep basalt aquifer exhibited contamination, predominantly RDX. RDX concentrations ranged from 27 to 5,640 μg/l.

2.4.4 Morrison Knudsen Environmental Services/CH2M HILL Supplemental Investigation

In November 1991, Morrison Knudsen Environmental Services/CH2M HILL completed four boreholes (numbered S4B-5 through SB4-8), two through each lagoon, to determine the vertical extent of contamination immediately below the lagoons (MKES/CH2M HILL, 1992). The borings extended to the top of the groundwater table (approximately 47 feet below the bottom of the lagoons). Soil samples were collected at 2-foot intervals for the top 10 feet and 5-foot intervals thereafter using an 18-inch split spoon sampler. All samples were analyzed for explosives. In addition, samples from the 0-foot, 4-foot, and 10-foot intervals were analyzed for volatile and semivolatile organics, polychlorinated biphenyls (PCBs), metals, and general physical/chemical parameters. The results were as follows:

- High concentrations of TNT and RDX (>100 μg/g to 980) were only detected in samples collected in the top 2 to 3.5 feet. Concentrations of TNT and RDX below that depth generally ranged from below detection (<1 μg/g) to 30 μg/g. Elevated concentrations of RDX (80 to 90 μg/g) were observed in S4B-7 at depths of 15 to 20 feet.

- HMX was detected in the majority of few samples, with a maximum observed concentration of 47 μg/g and an erratic distribution.

- TNB was detected in almost all samples at concentrations varying from 2 to 47 μg/g.

- 2,4-DNT and 2,6-DNT were detected less frequently, and at depths generally below 8 feet. Concentrations generally ranged from below detection (<1 μg/g) to 5 μg/g. A single higher concentration of 2,4-DNT (16 μg/g) was noted in S4B-7 at 15 feet, the same interval at which RDX was somewhat elevated. Tetryl was not detected.

- Concentrations of organic compounds other than the explosives discussed above were below detection.

- Inorganic compound concentrations were either below detection or within the range of typical soil background levels.

- The mean moisture content of the samples was 7.2 percent, with a range of 3.5 to 17.5 percent. The mean total organic carbon (TOC) was 2.63 g/kg, with a range of 0.84 to 7.34 g/kg.

2.4.5 Conclusions

The following conclusions were drawn from the available data:

- The contaminants most frequently detected in the soil are TNT, RDX, HMX, TNB, and 2,4-DNT. Tetryl, 2,6-DNT, DNB, and NB are rarely if ever detected.

- Contamination is present throughout the vertical extent of the unsaturated soil column (vadose zone) beneath both lagoons, although somewhat higher concentrations are generally observed in the south lagoon. RDX and TNT concentrations in the upper 2 to 3.5 feet of soil typically range from 100 to 2,000 μg/g; they are generally less than 30 μg/g below that depth. Very high TNT concentrations (45,582 μg/g and 87,623 μg/g) have been observed in the top inch of soil. HMX concentrations generally range from below detection (<1 μg/g) to 100 μg/g and TNB concentrations from 2 to 47 μg/g throughout the vadose zone. 2,4-DNT is generally detected only at soil depths below 6 feet, and then in low concentrations of approximately <1 μg/g (below detection) to 5 μg/g.

- There appears to be a minor subsurface "hot spot" in the western end of the south lagoon at a depth of 15 to 20 feet. RDX and 2,4-DNT

concentrations (80 to 90 μg/g and 16 μg/g, respectively) are elevated with respect to concentrations at the same depth in other borehole locations.

- The central berm exhibits high contaminant concentrations to a depth of 6 feet (coincident with the bottom of the lagoons). TNT concentrations range from 58 to 5,500 μg/g, while RDX concentrations range from 30 to 660 μg/g. The highest concentrations were observed in the top 2 feet of soil immediately below the movable flume. The perimeter berms generally exhibit low (less than 20 μg/g) contaminant concentrations.

- The number of detections and contaminant concentrations from subsurface samples collected immediately outside the lagoons are much lower than subsurface samples collected directly beneath the lagoons, indicating that there has been little lateral migration of contaminants through the vadose zone.

- Detections and contaminant concentrations at the groundwater interface both inside and outside the lagoons tend to be somewhat higher than in the vadose zone 20 feet above the interface, indicating that the deep vadose zone might be influenced by the groundwater.

- There is significant contamination of the alluvial aquifer. The most widely distributed groundwater contaminant is RDX, and it is present in

moderately high concentrations (1,000 to 10,000 μg/l is common). TNT and HMX are also present in high concentrations in wells near the lagoons, but they are not widely distributed (Dames & Moore, 1991).

- Explosives contamination predominantly consisting of RDX has been detected in the basalt aquifer, but there is insufficient data to determine if any contaminant plumes are present (Dames & Moore, 1992).

- Groundwater contamination trends cannot be correlated directly with soil contamination trends. For example, soil concentrations of RDX, which is the most widely distributed groundwater contaminant, are generally lower than soil concentrations of TNT.

2.5 Contaminant Fate and Migration

The analysis of fate and migration involves determining how a chemical will behave when it is released into the environment. This behavior can be described in terms of three classes of processes: transformation, transfer, and transport.

Transformation processes alter the chemical, either through physical, chemical, and/or biological reactions or by reaction with another chemical. Fate is the combination of

these transformation processes and controls how long a chemical will persist in the environment.

Transfer processes distribute a chemical between sectors of the environment. Transport processes act to redistribute a chemical within a given sector of the environment. For purposes of transport discussions, the environment is usually subdivided into four sectors: air, soil, groundwater, and surface water. In the following discussion, biota is included as an additional "sector." Migration is the combination of transport and transfer processes and controls the spatial and temporal distribution of a chemical with time.

The primary references for the following discussion of these processes are the Preliminary Assessment, Risk Assessment, and RI prepared by Dames & Moore (1990a, 1991, 1992). The physical and chemical properties of the explosives that form the basis for portions of the discussion are provided in Table 2-3.

2.5.1 Transformation Processes

Transformation processes alter contaminants such that they no longer exist either in the original form or as the original species. Dames & Moore (1991) reviewed numerous investigations of the transformation of explosives; mechanisms considered included photolysis, oxidation/reduction, hydrolysis, and biodegradation. A summary of that review is provided in Table 2-4.

Table 2-3
Physical and Chemical Properties of the Explosives[a]

	TNT	2,4-DNT	2,6-DNT	TNB	DNB	RDX	HMX	Tetryl
CAS Registry No.	118-96-7	121-14-2	606-20-2	99-35-4	99-65-0	121-82-4	2691-41-0	479-45-8
Empirical Formula	$C_7H_5N_3O_6$	$C_7H_6N_2O_4$	$C_7H_6N_2O_4$	$C_6H_3N_3O_6$	$C_6H_4N_2O_4$	$C_3H_6N_6O_6$	$C_4H_8N_8O_8$	$C_7H_5N_5O_8$
Molecular Weight	227.15	182.15	182.15	213.12	168.12	222.15	296.20	287.17
Density (g/cm^3)	1.65	1.521	1.538	1.63	1.575	1.83	1.90(β form)	1.73
Melting Point (°C)	80.75	72	66	122	90	205	286	129.5
Vapor Pressure (mm Hg, 25°C)	$5.51x10^{-6}$	$2.17x10^{-4}$	$5.67x10^{-4}$	$3.03x10^{-6}$	$1.31x10^{-4}$	$4.03x10^{-9}$	$3.33x10^{-14}$	$5.69x10^{-9}$
Aqueous Solubility (mg/L, 25°C)	150	280	206	385	533	60	5	80
Henry's Constant ($atm.m^3/mole$, 25°C)	$1.10x10^{-8}$	$1.86x10^{-7}$	$4.86x10^{-7}$	$2.21x10^{-9}$	$5.44x10^{-8}$	$1.96x10^{-11}$	$2.60x10^{-15}$	$2.69x10^{-11}$
Log K_{ow}	2.00	1.98	1.89	1.18	1.49	0.87	0.26	1.65
K (ml/g)[b]	1.00	0.68	0.21	2.23	0.45	0.21	0.44	0.71
R[b]	4.46	3.34	1.72	8.72	2.55	1.73	2.51	3.46
Bone concentration factor (BCF) (fish)	8.95	10.6	9.82	2.65	4.70	1.50	0.49	6.31

[a]Dames & Moore (1991) except where otherwise noted.
[b]From Dames & Moore (1992).

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Table 2-4
Summary of Environmental Transformation Processes of Selected Explosives[a]

Explosive	Photolysis	Oxidation/Reduction	Hydrolysis	Biodegradation	Principal Environmental Fate
TNT	In shallow surface water, photolysis may be the principal process for degradation. Degradation products depend on pH.[b]	Minimal susceptibility to oxidation/ reduction.	Not expected to be an environmental degradation pathway.[b]	If sufficient nutrients are present, many types of microbiota can degrade TNT to produce primarily amine and azoxy metabolites. Metabolites appear to be incorporated into humic material.[b]	Under composting conditions, biodegradation produces amine metabolites that become incorporated into humus. In shallow surface water, however, photolysis is the principal fate. High concentrations of TNT in soils lacking in abundant nutrients may inhibit the development of an acclimated microbiota.
2,4-DNT 2,6-DNT	In shallow surface water, photolysis may be important. Products stable to further photodegradation are not produced.[a]	Minimal susceptibility to oxidation/ reduction.	Similar to TNT.[b]	Both 2,4-DNT and 2,6-DNT are reported to be degraded by the microbiota from a munitions site, but at a somewhat slower rate than TNT.[b]	The environmental fate of 2,4-DNT and 2,6-DNT should be very similar to the fate of TNT.
TNB DNB NB	TNB appears to be stable to photodegradation. The stability of DNB and NB is uncertain.[a]	Minimal susceptibility to oxidation/ reduction.	Similar to TNT.[b]	TNB, DNB, and NB are reported to be degraded by microbiota, primarily to produce amine metabolites.[b]	TNB appears to be persistent in soil and groundwater. DNB and NB are degraded microbiologically but their mineralization is uncertain.
RDX HMX	In shallow surface water, RDX and HMX will be degraded within 7 to 10 days.[a]	Minimal susceptibility to oxidation/ reduction.	Similar to TNT.[b]	Both RDX and HMX are susceptible to biodegradation. For biodegradation to occur, there appears to be a need for significant nutrient augmentation.[a]	Biodegradation expected to occur under composting conditions. RDX may be persistent in soil and groundwater; the persistence of HMX is uncertain. In shallow surface water photolysis will degrade both explosives.
Tetryl	In shallow surface water, tetryl will be degraded to N-methylpicramide within 20 days.[a]	Minimal susceptibility to oxidation/ reduction.	The hydrolytic half-life is about 10 months. The products are picric acid and methylnitramine.[a]	Susceptibility unknown.	Although partial degradation may occur via photolysis or hydrolysis the fate of its degradation products is uncertain.

[a]From Dames & Moore (1991) except where noted.
[b]From Layton et al. (1987).

Photolysis appears to partially degrade TNT, 2,4-DNT, 2,6-DNT, RDX, and HMX in shallow surface water. The compounds typically undergo reduction of nitryl groups followed by oxidation of methyl groups. The primary photoproduct of TNT in natural surface water systems appears to be TNB, which is stable to further photodegradation; in laboratory studies, RDX and HMX appear to be photolyzed to produce nitrate and formaldehyde (Dames & Moore, 1991.) Degradation occurs within 1 to 3 weeks. This mechanism is effective only for dissolved substances present in the upper 7 to 8 inches of water.

The most significant mechanism for transforming explosives in soil and biota appears to be biodegradation. Varying degrees of biodegradation have been noted under conditions of liquid culture, soil culture, soil-water slurry, activated sludge, and composting. TNT is readily degraded to aromatic amine metabolites under aerobic conditions. In soil and water that have a high organic fraction, the metabolites are apparently incorporated into humic material and biomass via covalent bonding (Dames & Moore, 1991). The naturally occurring organic content of soil and water at UMDA is low, so the products of natural biodegradation may persist. DNT, DNB, RDX, and HMX have been shown to undergo varying degrees of biodegradation. Products include amine metabolites and hydroxylamines. RDX and HMX appear to require significant nutrient augmentation for degradation to occur.

There is no experimental evidence that abiotic oxidation or reduction of explosives contaminants occurs under ambient environmental conditions (Dames & Moore, 1991).

Reduction of nitro groups on the explosives may occur in anaerobic aquifers if sufficient organic matter is present.

Hydrolysis has been demonstrated only for tetryl; it is not considered a significant transformation mechanism for the explosives of concern.

2.5.2 Transfer Processes

Transfer of contaminants can potentially occur between any two sectors of the environment. Examples of transfer processes are adsorption-desorption (soil-water transfer) and volatilization (soil-air transfer). The direct transfer processes of potential significance at the Explosives Washout Lagoons include soil-to-water, soil-to-air, and soil-to-vegetation. Transfer of contaminants from soil to human receptors is considered in the baseline risk assessment presented in Section 2.6, and is not addressed here.

Soil-to-Water. The transfer of contaminants from the soil phase to the aqueous phase is generally governed by the soil:water partition coefficient, K_d. The K_d represents the distribution of a chemical between the two phases in saturated soil under equilibrium conditions; the higher the K_d, the greater the affinity for the soil phase. In soils at other military installations, values of K_d for the explosives of interest ranged from 2.3 to 11, with an average of 4 (Dames & Moore, 1991). Values were highest for clay; organic content did not appear to be as important as mineral content (Dames &

Moore, 1991). Site-specific K_ds for soil samples from the Explosives Washout Lagoons were measured in laboratory tests conducted by Dames & Moore (1992). The resulting values, shown in Table 2-3, are low, ranging from 0.21 for RDX and 2,6-DNT to 2.23 for TNB. The results indicate that the explosives have a relatively low tendency to adsorb onto the soil particles and should transfer readily from the soil phase to the aqueous phase.

Dames & Moore (1991) also evaluated the rates of contaminant transfer from the soil to the groundwater and the resulting contaminant concentrations that would be expected in the groundwater, assuming initial groundwater concentrations of zero. Calculations were based on the rate of precipitation (9 inches per year), the K_d of the explosives, and the total flow of groundwater beneath the lagoons. However, the calculations were very conservative in that they assumed that all of the precipitation falling on the lagoons (approximately 200,000 liters per year, or 54,000 gallons per year) percolated to the groundwater; in reality, a large volume of that rainfall probably evaporates, given that the potential evaporation rate for the region is over three times the precipitation rate. In addition, the calculation of the groundwater volume with which the soil leachate would be diluted was conservative, in that it was based on a flow velocity of about 50 feet per year; the actual velocity measured more recently by Dames & Moore (1992) is 160 to 1,100 feet per year, which would provide a larger dilution factor.

Given the low soil-to-water partitioning coefficient for site soils, explosives compounds have the potential to transfer rapidly from the soil to available water. However, given the low rainfall, high evaporation rate, and current absence of water discharges to the lagoons, it is unlikely that the rate of bulk transfer of contaminants through the soil to the groundwater is significant. Additional evaluation of this transfer pathway will be conducted as part of the installation-wide RI/FS.

Another mechanism for the transfer of explosives contaminants from the soil to the groundwater might be the leaching of explosives as suspended particulates. There is insufficient information on the form of the explosives to evaluate this pathway.

Soil-to-Air. The transfer of contaminants from soil to air can occur as a result of volatilization or the generation of contaminated dust and airborne particulates. The latter might occur by natural mechanisms (e.g., wind erosion) or by human activities (e.g., excavation). As shown in Table 2-3, the vapor pressures of the explosives are low, and the Henry's Constants indicate little tendency to volatilize. Wind erosion was evaluated by Dames & Moore (1991) on the basis of climatic and site conditions. Considering the two adjacent lagoons as a single 30- by 30-meter source, Dames & Moore calculated an annual soil emission rate of 6.3 milligrams soil per second (440 lb/yr). The generation of airborne contamination during the conduct of soil-disturbing activities was not evaluated, since it is presumed that appropriate surface controls would be used.

Soil-to-Vegetation. Two experimental studies on the bioaccumulation of TNT in plants were reviewed by Dames & Moore (1991). In addition, investigations into the bioaccumulation and phytotoxicity of TNT and RDX were conducted by Pacific Northwest Laboratory (PNL) and were reviewed during preparation of the FS (PNL, 1989; 1990). In all of the studies, there was clear evidence that both TNT and RDX are readily transferred from soil to plant tissues. This capacity for bioaccumulation appears to increase with increasing concentrations of explosives in hydroponic media and in soils (Dames & Moore, 1991; PNL, 1989, 1990).

The PNL investigations included evaluating the rate and extent of contaminant uptake. Three plant species were examined (bush bean, wheat, and bromo blando). Short-term studies with these were conducted using hydroponic solutions amended with either TNT or RDX; long-term studies involved growing the plants in soil amended with either TNT or RDX. Results varied significantly depending on the soil composition; uptake was greatest for plants grown in the sandy-silty Burbank soil, which had a low organic carbon content (less than 0.5 percent) (PNL 1989, 1990). Of the three soils used, Burbank soil most closely resembles the soil from the UMDA lagoons with its mean organic content of 0.3 percent (MKES/CH2M HILL, 1992).

Results with the hydroponic systems showed that the absorption capacity for plants is high (PNL, 1989). After absorption, greater than 75 percent of the accumulated TNT and residues is retained within the root (PNL, 1989). RDX is absorbed through the roots, but within 7 days only 20 percent of the total amount accumulated in the plant

remains in the roots; the remainder accumulates preferentially in the new growth (seeds and shoots), then in the leaves and stems of plants (PNL, 1990). The following specific results were obtained from studies in which plants were grown on the Burbank soil amended with 10 ppm of the explosive under consideration:

- Average TNT concentrations in roots ranged from 59 to 217 ppm (fresh weight); concentrations in shoots were 54 to 65 ppm (fresh weight); concentrations in leaves and stems were 9 and 24 ppm, respectively (fresh weight); and seed concentrations averaged 0.55 ppm (fresh weight).

- Average RDX concentrations in roots ranged from 28 to 75 ppm (fresh weight); concentrations in shoots ranged from 550 to 564 ppm (fresh weight); leaf and stem concentrations were 217 and 187 ppm, respectively (fresh weight); and average seed concentrations were 603 ppm (fresh weight).

Based on the tissue accumulation patterns, RDX exhibited greater plant mobility. In addition, RDX uptake was substantially higher, with whole-plant concentration ratios (tissue concentration per unit weight/soil concentration per unit weight) ranging from 20 to 50 on a fresh weight basis (PNL, 1990).

2.5.3 Transport Processes

As described earlier, transport processes are those by which a chemical is redistributed within a single environmental medium. The two most common are advection and dispersion. Transport of contaminants through the soil is generally accomplished via transfer to the aqueous phase followed by aqueous transport as described in the earlier discussion of soil leaching. Transport via groundwater and air are discussed below.

Groundwater. Contaminants might be transported by the groundwater either in solution or as particulates entrained in the water. The rate at which contaminants travel can be described by the retardation factor (R). R is a measure of how much more slowly a contaminant moves than the groundwater; if R equals 5, the contaminant moves at one-fifth the speed. Dames & Moore calculated values of R for the UMDA site from the properties of soils collected from the shallow aquifer below the Explosives Washout Lagoons. The results are shown in Table 2-3. The values of R are not particularly high (1.7 to 8.7 [unitless]); for comparison, highly adsorbed contaminants may have R values of 400 or more (Dames & Moore, 1992). Of the contaminants seen in the highest concentrations in soil at the lagoons (TNT, RDX, HMX), RDX has the lowest R value and is expected to be the most mobile compound in groundwater.

Other parameters that affect the mobility of a contaminant in groundwater were evaluated by Dames & Moore (1992) based on pumping tests and slug tests. They

include the groundwater velocity, the hydraulic conductivity, and the transmissivity of the aquifer. The groundwater velocity beneath the lagoons was calculated to be 160 to 1,100 ft/year. The hydraulic conductivity in the sands and gravels near the top of the unconfined aquifer was about 0.7 ft/min, typical for clean sand and gravel (Dames & Moore, 1992). In silts and silty sands deeper in the unconfined aquifer the hydraulic conductivity decreases. The transmissivity of the unconfined aquifer was estimated to be about 8 ft/min (Dames & Moore, 1992). Total porosity of the soils near the lagoons was between 0.33 and 0.60; the effective porosity (open space between grains) was assumed to be 0.2.

Air. The initial transfer of contaminants from soil to air was discussed in Section 2.5.2. While the atmospheric dispersion of these contaminants could potentially affect onsite workers, offsite populations are unlikely to be affected in the near-future because the lagoons are located at least one mile from the boundary of the installation. As part of the Risk Assessment, Dames & Moore modeled the dispersion of dust generated at the lagoons (Dames & Moore, 1991). Based on the prevailing wind, dispersion would occur predominantly to the northeast, east, and southeast (Dames & Moore, 1991). The initial atmospheric dust concentration at the lagoons was 1.96×10^7 pg/m^3. The maximum concentration observed 100 meters from the lagoons was 3.95×10^5 pg/m^3, and at 500 meters it was 2.37×10^4 pg/m^3 (Dames & Moore, 1991).

2.6 Baseline Risk Assessment

This section summarizes the baseline Risk Assessment (RA) for the UMDA Explosives Washout Lagoons soils conducted by Dames & Moore and documented in *Draft Final Interim Risk Assessment for the Explosive Washout Lagoon (Site 4), Umatilla Depot Activity, Hermiston, Oregon* (Dames & Moore, 1991). That document is the primary reference throughout the following discussion except where noted. The focus of this risk assessment is the human health risk associated with direct contact with the soil. Ecological risks are discussed in the following section.

2.6.1 Selection of Contaminants of Concern

Soil and groundwater samples collected from 1988 through 1990 were analyzed for nine explosives. These explosives were designated contaminants of potential concern if detected in at least one sample from soils or groundwater. Ambient air was not analyzed.

Historical use of the lagoons was the primary rationale for excluding chemicals other than explosives. Recent sampling at the lagoons has verified that other organic chemicals are not present at detectable concentrations, and that inorganic constituents are present in levels comparable to natural background (MKES/CH2M HILL, 1992).

Seven of the nine explosives were identified as contaminants of concern in lagoon soils. They are:

- 1,3,5-Trinitrobenzene (TNB)
- 1,3-Dinitrobenzene (DNB)
- 2,4,6-Trinitrotoluene (TNT)
- 2,4-Dinitrotoulene (2,4-DNT)
- HMX
- Nitrobenzene (NB)
- RDX

Two explosives, tetryl and 2,6-DNT, were not listed as chemicals of potential concern in the soil because of the low frequency and low concentrations of detections.

2.6.2 Exposure Assumptions

The probability of current exposure of human receptors to the contaminants of concern at the Explosives Washout Lagoons was considered low because of access restrictions and was therefore not evaluated in the RA. The probability of future exposure of human receptors was considered high based on the probability that the UMDA property will eventually be vacated by the Army and become available for residential or industrial use. Three future land use scenarios were evaluated in the RA:

- Residential
- Light industrial
- Military

The light industrial land use scenario is considered the most probable scenario for future use of UMDA. Both it and the residential use scenario are discussed in the following sections. EPA has not approved a standardized military use scenario, and use of the military use scenario would in any case not be consistent with the remedial goals for the site. Therefore, the results of the assessment of the military use scenario are not presented in this FS.

For each land use scenario, four exposure pathways were evaluated:

- Incidental ingestion of soil
- Dust inhalation
- Dermal absorption of chemicals in soil
- Groundwater ingestion

The probability of significant exposures by other pathways was considered low.

The RA used exposure factors obtained from *Risk Assessment Guidance for Superfund* (EPA, 1989) and guidance supplemental to that document (EPA, 1990; EPA, 1991b; EPA, 1991c).

Soil Ingestion Exposure Pathway. Soil concentrations of the chemicals of concern were assumed to be the 95 percent upper confidence limit on the arithmetic mean of surface soil data (less than 2 feet deep), including data collected by Roy F. Weston, Inc. It should be noted that these concentrations are conservatively high, since the Weston samples were purposely collected at locations that were more visibly discolored than the average. For chemicals detected in at least one sample, nondetects in other samples were replaced with the detection level for calculating exposure point concentrations. However, for 1,3-DNB and NB that were not detected in any surface soil samples, the exposure point concentrations were assumed to be one-half the detection limit. Furthermore, although the 95 percent confidence limit on the arithmetic mean was assumed to represent the exposure point concentrations for the other chemicals detected, the maximum measured concentrations were assumed to be the exposure point concentrations for TNT, RDX, HMX, 1,3,5-TNB, and 2,4-DNT.

Soil ingestion was assumed to be inversely proportional to body weight. Both children and adults were evaluated.

Dust Inhalation Exposure Pathway. Ambient air concentrations of the chemicals of concern were obtained by modeling wind erosion of lagoon soils and assuming that the exposure point concentrations were equivalent to the modeled concentrations of dust-borne chemicals.

For the residential land use scenario, the RA only evaluates adult receptors under the dust inhalation pathway, based on the assumption that the uptake rate by dust inhalation is directly proportional to body weight. For the light industrial land use scenario, the exposure assumptions were obtained from EPA (1990; 1991c).

Dermal Absorption of Soil Contaminants Exposure Pathway. The chemical-specific soil absorption factor was used to represent the desorption of chemical from soil and subsequent absorption of chemical across the skin and into the blood of the exposed individual. For RDX, this factor was assumed to be zero percent based on studies demonstrating that it is not absorbed through skin. For all other chemicals of concern, the soil absorption factor was assumed to be 50 percent based on EPA guidance for cases where absorption data is not available.

For the residential land use scenario, risks to human health were evaluated separately for adults and children because skin surface area, exposure frequency, and body weight are age dependent.

The light industrial land use scenario was evaluated using an exposure frequency of 36 percent to account for the assumption that future workers at the lagoon site would be exposed to the chemicals of concern less frequently than residents.

Groundwater Ingestion Exposure Pathway. The exposure point concentrations for groundwater ingestion were assumed to be the 95 percent upper confidence limit on

the arithmetic mean of the groundwater chemical data collected by Roy F. Weston, Inc., and Dames & Moore.

The assumptions for exposure frequency, exposure duration, and fraction ingested were revised for the light industrial land use scenario to account for worker exposures that are expected to be less frequent and of shorter duration than residential exposures.

In accordance with the EPA guidance, the RA assumes that children would not be evaluated under this pathway because the intake of contaminants by groundwater ingestion is not strongly age dependent.

2.6.3 Toxicity Assessment

The carcinogenicity of the chemicals of concern at UMDA was evaluated on the basis of cancer slope factors available on the IRIS or HEAST data bases. Slope factors were available for 2,4,6-TNT, 2,4-DNT, and RDX, and the 2,4-DNT slope factor was applied to 2,6-DNT. Chemicals of concern for which slope factors were not available were not evaluated for carcinogenicity. The potential for the development of noncancerous adverse health effects was evaluated on the basis of reference doses (RfDs) available on the IRIS or HEAST data bases or in EPA (1991b). Reference doses were available for all of the chemicals of concern. The EPA toxicity values for each chemical of concern, including weight-of-evidence classification and cancer type (if

carcinogenic), confidence level, critical effect(s), and uncertainty factors are provided in Table 2-5.

Oral absorption of all chemicals was assumed to be 100 percent; dermal absorption was assumed to be 50 percent. Toxicity data indicate that RDX is not absorbed by the dermal route, so dermal exposure was not considered. Summaries of the investigations upon which oral and dermal absorption were based are provided in Tables 2-6 and 2-7. Abbreviated qualitative toxicity profiles for the chemicals of concern are provided below.

1,3,5-TNB. Methemoglobin forms after oral administration in animals. Hyperemia, edema, and hemorrhages followed dermal application. Eye irritation followed ocular exposure.

1,3-DNT. Rapidly absorbed through the skin; chronic worker exposures produced weakness, cyanosis, and anemia.

2,4,6-TNT. Absorbed in the gastrointestinal tract, skin, and lungs. Reproductive effects reported in studies of animals included testicular atrophy and degeneration of the seminiferous tubular epithelium. Jaundice and hepatitis followed acute poisoning of humans. Chronic worker exposures produced cataracts, neurasthenia, polyneuritis, and

Table 2-5
Health Effects Criteria for Contaminants of Concern
Explosives Washout Lagoons (Site 4), UMDA

Contaminant of Concern	Slope Factor (mg/kg-day)-1	Source	Weight of Evidence Classification	Cancer Type	Reference Dose (mg/kg-day)	Source	Critical Effect	Uncertainty Factor	Confidence Level
1,3,5-Trinitrobenzene					5.00E-05	IRIS	Increased splenic weight	10,000	low
1,3-Dinitrobenzene					1.00E-04	IRIS	Increased splenic weight	3,000	low
2,4,6-Trinitrotoluene	0.030	IRIS	C	urinary bladder papillomas	5.00E-04	IRIS	Liver effects	1,000	medium
2,4-Dinitrotoluene	0.680	HEAST	B2	liver, mammary gland	6.00E-04	USEPA, 1991c	Hepatic alterations	1,000	low
2,6-Dinitrotoluene	0.680	HEAST	B2	(a)	1.00E-03	USEPA, 1991c	Liver, kidney, neurological, reproductive and hematological effects	3,000	low
HMX					5.00E-02	IRIS	Hepatic lesions	1,000	low
Nitrobenzene					5.00E-04	IRIS	Hematologic, adrenal, renal, and hepatic lesions	10,000	low
RDX	0.110	HEAST	C	hepatocellular carcinomas and adenomas	3.00E-03	IRIS	Inflammation of prostate	100	high
Tetryl					1.50E-03	Small, 1988	Skin sensitization	100	low

Sources: IRIS: Integrated Risk Information System, January 1991.
HEAST: Health Effects Assessment Summary Tables, 4th Quarter, September 1990.
EPA, 1991c: Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors
Small, 1988: Residual Explosives Criteria for Treatment of Area P Soil, Louisiana Army Ammunition Plant

(a) Based on potential carcinogenicity of 2,4-DNT.

Table 2-6
Oral Absorption Factors for Contaminants of Concern
Explosives Washout Lagoons (Site 4), UMDA

Chemical	EPA Documents	ATSDR Profiles (1989)
Dinitrotoluenes (DNTs): 2,4-DNT; 2,6-DNT; 2,4/2,6-DNT mixture (technical grade DNT)	U.S. EPA, 1987: Animals: 60-90% for various DNTs with 2,4-DNT absorbed more readily than 2,6-DNT. 8-12% for 2,4-DNT in mice. 75-85% for 2,4-DNT in rats, rabbits, dogs, and monkeys.	Animals: Based on urinary excretion data: Absorption was at least 55-90% for DNTs in rats, rabbits, beagle dogs, and rhesus monkeys; at least 50% for 2,6-DNT in mice; at least 10% for 2,4-DNT in mice.
HMX	No EPA documents.	No ATSDR profile for this chemical.
RDX	U.S. EPA, 1989a: Animals: Almost completely absorbed in rats.	No ATSDR profile for this chemical.
Trinitrobenzene	U.S. EPA, 1989b: No quantitative data. Some absorption is inferred based on oral LD50 values.	No ATSDR profile for this chemical.
TNT (2,4,6-Trinitrotoluene)	U.S. EPA, 1990: Animals: Absorption in several species ranges from at least 42% to at least 74% (based on urinary excretion data). U.S. EPA 1989c: Animals: Absorption in several species ranges from at least 45% to at least 82% (based on urinary excretion and tissue levels).	No ATSDR profile for this chemical.

References:

ATSDR. 1989. Toxicological Profile for 2,4- and 2,6-Dinitrotoluene. Agency for Toxic Substances and Disease Registry. U.S. Public Health Service. Atlanta, Georgia.

U.S. EPA. 1987. Health Effects Assessment for 2,4- and 2,6-Dinitrotoluene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, Ohio, for the Office of Emergency and Remedial Response, Washington, D.C.

U.S. EPA. 1989a. Health and Environmental Effects Document for RDX Cyclonite. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, Ohio, for the Office of Solid Waste and Emergency Response, Washington.D.C.

U.S. EPA. 1989b. Health and Environmental Effects Document for 1,3,5-Trinitrobenzene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, Ohio, for the Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. EPA. 1989c. Trinitrotoluene. Health Advisory. Office of Drinking Water, Washington, D.C.

U.S. EPA. 1990. Health and Environmental Effects Document for 2,4,6-Trinitrotoluene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, Ohio, for the Office of Solid Waste and Emergency Response, Washington, D.C.

Source: EPA, 1991e.

Table 2-7
Dermal Absorption Factors for Contaminants of Concern
Explosives Washout Lagoons (Site 4), UMDA

Chemical	EPA Documents	ATSDR Profiles (1989)
Dinitrotoluenes (DNTs): 2,4-DNT; 2,6-DNT; 2,4/2,6-DNT mixture (technical grade DNT)	U.S. EPA, 1986: Limited data suggest that 2,4-DNT is readily absorbed through the skin, but the extent of absorption has not been reported.	Two studies of occupational exposure to 2,4/2,6-DNT mixture have suggested that dermal absorption can be a significant route of entry for these isomers in humans.
HMX	No EPA documents.	No ATSDR profile for this chemical.
RDX	U.S. EPA, 1989a: Not absorbed through the skin. Further information or documentation was not provided.	No ATSDR profile for this chemical.
Trinitrobenzene	U.S. EPA, 1989b: No data. No other EPA documents.	No ATSDR profiles for this chemical.
Trinitrotoluene	U.S. EPA, 1990: Animals: Absorption of 16-18% in the dog, 23-25% in the rate, 42% in the mouse and 57-68% in the rabbit. U.S. EPA 1989c: Animals: Same as U.S. EPA, 1990.	No ATSDR profile for this chemical.

References:

ATSDR. 1989. Toxicological Profile for 2,4- and 2,6-Dinitrotoluene. Agency for Toxic Substances and Disease Registry. U.S. Public Health Service. Atlanta, Georgia.

U.S. EPA. 1987. Health Effects Assessment for 2,4- and 2,6-Dinitrotoluene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, Ohio, for the Office of Emergency and Remedial Response, Washington, D.C.

U.S. EPA. 1989a. Health and Environmental Effects Document for RDX Cyclonite. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, Ohio, for the Office of Solid Waste and Emergency Response, Washington.D.C.

U.S. EPA. 1989b. Health and Environmental Effects Document for 1,3,5-Trinitrobenzene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, Ohio, for the Office of Solid Waste and Emergency Response.

U.S. EPA. 1989c. Trinitrotoluene. Health Advisory. Office of Drinking Water, Washington, D.C.

U.S. EPA. 1990. Health and Environmental Effects Document for 2,4,6-Trinitrotoluene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, Ohio, for the Office of Solid Waste and Emergency Response, Washington, D.C.

Source: EPA, 1991e.

other lesions of the central nervous system (CNS). Hematological effects include aplastic anemia and methemoglobinemia. TNT is also associated with sensitization dermatitis.

2,4-DNT. Methemoglobinemia, jaundice, anemia, and neuromuscular disorders followed exposure of animals to 2,4-DNT. Reproductive effects reported in animals were not observed in epidemiological studies of humans.

2,6-DNT. May be a promoter and initiator of hepatocarcinogenesis; no cancer data in humans is now available. Decreased spermatogenesis was observed in studies of animals exposed to 2,6-DNT.

HMX. Toxicity information is limited to a study of the lethal dose to 50 percent of the population (LD50) in animals and a 13-week feeding study in rats. Toxic effects were not noted in this risk assessment.

Nitrobenzene. Eye and skin irritation, CNS effects, liver and spleen effects, and methemoglobinemia have been observed in studies of animals exposed to nitrobenzene.

RDX. Oral and inhalation exposure of humans to RDX has been associated with seizures, lethargy, nausea, insomnia, irritability, and memory loss. Oral exposure of animals has been associated with prostatitis, hepatotoxicity, myocardial degeneration, renal toxicity, and cataracts.

Tetryl. Animals exposed to tetryl developed kidney damage and respiratory difficulties.

2.6.4 Risk Characterization

The excess cancer risks and the noncancerous hazard indices were calculated for each of the four pathways and two exposure scenarios, with the assumption that no remediation of soils or groundwater takes place. The results are summarized in Table 2-8. Cumulative risks are shown for direct contact with soil, with and without the additional risk associated with the ingestion of currently contaminated groundwater. Excess cancer risks are based on TNT, RDX, and 2,4-DNT. All chemicals of concern are assumed to contribute to the hazard indexes.

If no soil remediation occurs, the excess cancer risks associated with direct soil contact in a given exposure scenario would be as follows:

- Residential, 1.00×10^{-2}
- Light Industrial, 4.70×10^{-3}

Table 2-8 Summary of Carcinogenic and Noncarcinogenic Risks[a]				
	Residential Use		Light Industrial Use	
Pathway	Cancer Risks[b]	Noncancer Risks[c]	Cancer Risks[b]	Noncancer Risks[c]
Ingestion	1.77E-03	1120	3.33E-04	40.5
Inhalation	1.20E-05	0.66	4.9E-06	0.60
Dermal Contact	8.23E-03	3067	4.36E-03	546
Combined Pathways, Direct Contact with Soil Only	1.00E-02	4188	4.7E-03	587
Groundwater Ingestion	4.15E-03	64.8	1.23E-03	37.3
Combined Pathways, Soil and Groundwater	1.42E-02	4253	5.97E-03	624

[a]Concentrations used to calculate risks were derived from surface samples collected in the lagoons.
[b]Excess lifetime cancer risk to an individual.
[c]Hazard index (a hazard index of 1.0 or lower indicates that no adverse effects would be expected).

The noncancer hazard indexes associated with direct soil contact in a given exposure scenario are as follows:

- Residential, 4188
- Light Industrial, 587

The risk associated with direct contact with the soil is dominated by dermal contact.

2.6.5 Risk-Based Remedial Action Criteria

Potential risk-based remedial action criteria (RACs), also referred to as preliminary pollutant limit value (PPLV), were calculated based on direct contact with lagoon soils. RACs for the contaminants of concern were based on the soil concentrations equivalent to excess cancer risks of 1×10^{-6}, 1×10^{-5}, and 1×10^{-4}, and for noncancer risks on hazard indexes of 0.1, 1, and 10.

For each pathway of exposure related to soil at the Explosive Washout Lagoons, a single pathway PPLV (SPPPLV) was calculated, and from these values a PPLV for multiple pathway exposure was calculated according to the following equation:

$$PPLV = 1/(1/SPPLV_1 + 1/SPPLV_2 + ... + 1/SPPLV_n)$$

The RACs calculated for multiple pathway exposures for the explosives at the UMDA Explosives Washout Lagoons are presented in Table 2-9. These RACs are theoretical and do not consider technical limitations. If subsequent evaluations demonstrate that the risk-based RACs are below the capability of existing technology, best available technology would be used in conjunction with the risk evaluation to develop RACs.

Table 2-9
Summary of Risk-Based Remedial Action Criteria for Multiple Pathway Direct Contact Exposure for the Explosives Washout Lagoons (Site 4) for Residential and Light Industrial Land Use Scenarios

	Contaminant Concentrations (µg/g) versus Excess Cancer Risk Levels					
	Residential Land Use Scenario			Industrial Land Use Scenario		
Analyte	1.00E-04	1.00E-05	1.00E-06	1.00E-04	1.00E-05	1.00E-06
1,3,5-TNB	--	--	--	--	--	--
1,3-DNB	--	--	--	--	--	--
2,4,6-TNT	396	40	4.0	837	84	8.4
2,4-DNT	17	1.7	0.17	37	3.7	0.37
HMX	--	--	--	--	--	--
NB	--	--	--	--	--	--
RDX	620	62	6.2	3,250	325	33

	Contaminant Concentrations (µg/g) versus Hazard Indices					
	Residential Land Use Scenario			Industrial Land Use Scenario		
Analyte	HI = 0.1	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10
1,3,5-TNB	0.10	0.96	9.6	0.67	6.7	67
1,3-DNB	0.19	1.9	19	1.3	13	133
2,4,6-TNT	0.95	9.5	95	6.7	67	667
2,4-DNT	1.1	11	114	8.0	80	800
HMX	95	946	9,458	667	6,669	66,687
NB	1.0	10	95	6.7	67	667
RDX	22	217	2,174	572	5,723	57,227

Note: From Dames & Moore (1991).

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2.7 Ecological Risk Assessment

An installation-wide ecological risk assessment is being conducted as part of the UMDA RI/FS (Dames & Moore, 1992). Results for the Explosives Washout Lagoons were not yet available. However, qualitative observations regarding current conditions at the lagoons are noted below, along with the results of non-site-specific laboratory and field studies of the phytotoxicology of explosives-contaminated soil.

At present, the bottoms and sidewalls of the lagoons and the berms enclosing and separating the lagoons are devoid of virtually all vegetation, although plant growth typical of the high desert climate is well-established in the area surrounding the lagoons. The absence of plant growth in the lagoons themselves might be at least partially attributed to the presence of high explosives concentrations (greater than 1000 ug/g) in the surface soils. However, other factors, such as the presence of a large fraction of gravel in the berms and the lagoon bottoms, might also be retarding plant growth.

The rate and extent of the uptake of TNT and RDX in plants were investigated by PNL, as discussed in Section 2.5.2 (PNL, 1989; 1990). In addition, PNL conducted experiments to evaluate the potential phytotoxicity of TNT and RDX. For individual TNT experiments, the soil was amended to final concentrations of 0, 10, 30, and 60 ppm TNT. For the RDX studies, the soil was amended to final concentrations of 0, 10, 25, or 50 ppm RDX. Pots of soil were then planted with bush bean, wheat, or

bromo blando (grass) and the plants were allowed to grow for 60 days, or until maturity. During this period, the plants were observed for phytotoxic effects. In addition, biomass data were collected during the RDX studies.

The results from the TNT studies were as follows:

- A 50 percent reduction in plant height was observed in all species at a soil concentration of 60 ppm TNT; plant height was reduced by about 25 percent in the wheat and grass at a soil concentration of 30 ppm TNT (PNL, 1989).

- The grass exhibited marked chlorosis at the 60-ppm level and tip burn at both the 30-ppm and the 60-ppm levels (PNL, 1989).

- No phytotoxic effects were observed at the 10-ppm level.

The results from the RDX studies were as follows:

- Chlorosis and a 50 percent reduction in plant height were observed in all species at a soil concentration of 50 ppm RDX; plant height was reduced by about 15 percent in all species at a soil concentration of 25 ppm RDX (PNL, 1990).

- No phytotoxic effects were observed at the 10-ppm level.

- In the biomass studies, wheat and bromo blando grown in 10-ppm amended soils exhibited reductions in biomass of 15 to 50 percent. Reductions in biomass were not observed in the bush bean.

The phytotoxicity of explosives was also observed qualitatively during an ecological assessment under field conditions at the West Virginia Ordnance Works (Environmental Science and Engineering, Inc., 1986). Marked stress was noted in the vegetation where soil concentrations exceeded 100 ppm total nitroaromatic explosives; soil areas with greater than 1,000 ppm nitroaromatics were devoid of vegetation.

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Identification and Screening of Technologies

Chapter 3

Identification and Screening of Technologies

The purpose of this phase of the FS is to develop an appropriate range of remedial options that then will be evaluated more fully in the detailed analysis phase of the FS. The process used to accomplish this consists of first identifying the following:

- The applicable, or relevant and appropriate, requirements that affect remedy selection

- The remedial action objectives

- The areas and volumes of material requiring remediation

- The general response actions, remedial technologies, and process options that could address the remedial action objectives

The latter are then screened, first for general technical feasibility, then on the basis of effectiveness, implementability, and cost. Finally, remedial alternatives are developed out of the more promising options.

3.1 Applicable or Relevant and Appropriate Requirements

Section 121(d)(2)(A) of CERCLA incorporates into law the CERCLA Compliance Policy, which requires that Superfund remedial actions must meet or exceed any federal standards, requirements, criteria, or limitations that are determined to be legally applicable, or relevant and appropriate, requirements (ARARs). State requirements must also be met if they are more stringent than federal requirements.

"Applicable" requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA cleanup site. Applicability implies that the remedial action or the circumstances at the site satisfy all of the jurisdictional prerequisites of a requirement.

"Relevant and appropriate" requirements are cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that, while not applicable to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstances at a remedial action site, address problems or situations that are sufficiently similar such that their use is suited to the particular site. However, in some circumstances a requirement might be relevant but not appropriate for the site-specific situation. In that case, it is not considered an ARAR.

Other nonpromulgated policies, guidance, and directives may also be incorporated into the evaluation of remedial actions. These are termed to-be-considered (TBC) materials. Although they do not have specific regulatory authority, TBC materials may be used when ARARs are not available or not adequate to achieve a protective remedy.

Onsite CERCLA response actions must comply only with the substantive requirements of ARARs [CERCLA Section 121(e)]. It is presumed that CERCLA procedural requirements provide administrative safeguards similar to those provided under other laws. The NCP explicitly states that permitting requirements promulgated under other laws need not be implemented for remedial actions conducted solely at the site.

The selection of ARARs depends on the hazardous substances present at the site, the site characteristics and location, and the actions selected for a remedy. Thus, these requirements might be chemical-, location-, or action-specific. Chemical-specific ARARs are health- or risk-based concentration limits set for specific hazardous substances. Location-specific ARARs address such circumstances as the presence of an endangered species on the site or the location of the site in a floodplain. Action-specific ARARs control or restrict particular types of remedial alternatives such as incineration.

3.1.1 Chemical-Specific ARARs

The first step in identifying chemical-specific ARARs is identifying the chemicals of potential concern. To begin the identification process, the concentration and toxicity of the chemicals detected are evaluated, and each chemical is assigned a risk factor. The final selection of contaminants of concern is based on evidence of human carcinogenicity, frequency of occurrence in the soil, exceedance of acceptable intake values, exceedance of background levels, and environmental persistence and mobility. Using this process, Oak Ridge National Laboratory (ORNL) identified the following explosives as potential contaminants of concern in the lagoon soils (ORNL, 1991a):

- TNT
- RDX
- HMX
- NB
- DNB
- TNB
- 2,4-DNT

These compounds might be of concern because they pose potential human health risks if ingested, inhaled, or absorbed through the skin. Based on risk calculations, TNT presented 90 percent of the noncarcinogenic risk to human health from soil contamination, and TNT and RDX together presented 97 percent of the carcinogenic

risk (ORNL, 1991a). Tetryl and 2,6-DNT were not identified as potential contaminants of concern, tetryl because it has not been detected in any soil samples to date, and 2,6-DNT because of very infrequent and low-concentration detection.

Soil Cleanup Standards. Soil cleanup standards for individual chemical contaminants have not been promulgated under either federal or State of Oregon laws. In November 1991, the state formally proposed new soil cleanup standards for 77 hazardous substances. The proposed rule would provide standards for cleanups under both residential and industrial use scenarios, based on a residual excess cancer risk of 1×10^{-6}. Formal adoption of this rule is not expected until mid-1992 or later, so it cannot be considered an ARAR. In any case, the rule does not include any of the seven explosives identified as contaminants of concern.

The Oregon Hazardous Waste Remedial Action Act does provide a process for determining contaminant cleanup levels on a site-specific basis. ODEQ has indicated that this process should be considered an ARAR (ODEQ, 1991). The process is implemented as follows:

- In the event of a release of a hazardous substance, the environment shall be restored to background level (i.e., the concentration naturally occurring prior to any release from the facility) [OAR 340-122-040(2)(a)]

- When attaining background is not feasible, the acceptable cleanup level in the soil shall be the lowest concentration level that satisfies both the "protection" and "feasibility" requirements in OAR 340-122-090(1). The party responsible for the contaminated site is responsible for demonstrating the non-feasibility of attaining background.

The explosives constituting the contaminants of concern at the Explosives Washout Lagoons are not naturally occurring. Therefore, the background concentration would be essentially zero or, for practical purposes, below detection limits. If a remedial alternative proposed in this FS cannot achieve background, a risk assessment approach must be used to demonstrate that the action achieves the lowest cleanup level that protects human health and the environment.

Groundwater Cleanup Standards. Groundwater cleanup standards have been promulgated under Oregon's Groundwater Quality Protection Regulations (OAR 340-40), and drinking water standards have been established under the National Primary Drinking Water Regulations (40 CFR 141), Subpart B, Maximum Contaminant Levels. However, neither of these regulations includes numerical values for the explosives of concern.

RCRA Treatment Standards. Waste treatment standards that often include contaminant concentration criteria have been established under RCRA for certain hazardous wastes that are otherwise banned from land disposal (40 CFR 268). Since some of the

remedial options could involve treatment of the soil and subsequent land disposal, the RCRA requirements were reviewed to determine if they would be ARARs and result in chemical-specific treatment standards.

The contaminated soil was evaluated using the RCRA waste designation process outlined in 40 CFR Part 261. The soil is not in and of itself a waste, but it received and was contaminated by explosives waste from the Explosives Washout Plant. Two RCRA waste listings, K044 and K047, specifically apply to explosives wastes: K044 applies to wastewater treatment sludges generated during the original manufacture and loading, assembling, and packing of reactive explosives (such as TNT, RDX, and HMX), and K047 applies to wastes generated during the production and formulation of TNT and TNT-containing products (EPA, 1982). The operations at the Explosives Washout Plant did not involve the manufacturing, loading, assembling, or packing of explosives, nor the production and formulation of TNT compounds. Therefore, the wastes formerly generated at the washout plant did not meet the definition of listed wastes and the RCRA requirements, and are not legally applicable.

Furthermore, the K044 and K047 wastes are listed solely for the characteristic of reactivity and not for specific chemical constituents. A material can exhibit the characteristic of "reactivity" in several ways as defined by RCRA. For explosives, the following two definitions of a reactive material are applicable:

- It is capable of detonation or explosive reaction if it is subjected to a strong initiating source or if heated under confinement [40 CFR 261.23(a)(6)]

- It is readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure [40 CFR 261.23(a)(7)]

Extensive testing has been conducted by the Army to define the reactivity of explosives-contaminated soil to flame and shock stimuli. The explosives evaluated included TNT, RDX, and HMX. The results indicated that soil containing less than 15 percent explosives will not react positively to induced shock, and soil containing less than 12 percent explosives will not react explosively when subjected to submerged flame initiation (Arthur D. Little, Inc., 1987). As a conservative guideline, the Army generally uses a total explosives concentration of 10 percent as a control limit (USATHAMA, 1991b). The maximum concentration of explosives detected in any soil sample was about 89,000 μg/g, or 8.9 percent, and most samples were below 1 percent, well below reactive levels. Since the K044 and K047 wastes were listed because of the characteristic of reactivity and the soils are not reactive, the RCRA requirements are also not judged to be appropriate. They will be classified here as TBC guidance because the waste disposed of to the lagoons was similar to the RCRA-listed wastes.

3.1.2 Location-Specific ARARs

Federal and state laws and regulations that were reviewed to identify location-specific ARARs are listed in Table 3-1. Location-specific considerations are discussed below.

Seismicity. UMDA is surrounded by four structural features: the Service Anticline on the east, an anticline on the west, the Dalles-Umatilla Syncline to the north, and a monocline to the south (Dames & Moore, 1990a). There is faulting on the Service Anticline, but it is not believed to have been displaced during the Holocene period, nor is it considered active (ORNL, 1991a). The area has a history of low seismicity (ORNL, 1991a) and therefore no ARARs were determined to be significant in this category.

Wilderness Areas, Wildlife Refuges, and Scenic Rivers. There are no designated wilderness areas within UMDA or in its immediate vicinity (ORNL, 1991a). Neither the Columbia nor the Umatilla River has been designated as a scenic river (ORNL, 1991a). Therefore, there are no ARARs associated with these location categories (ORNL, 1991a).

However, there are three wildlife refuges within 15 miles of UMDA. One of these, Irrigon State Wildlife Refuge (2 miles), is considered a sensitive environment and one of the primary wetlands in the region (ORNL, 1991a). For soil remedial actions that are performed onsite, no ARARs would develop because UMDA itself is not located

Table 3-1
Review of Potential Location-Specific ARARs
Umatilla Depot Activity Explosives Washout Lagoons

Location	Citation	Requirement	Preliminary ARAR designation
Seismicity	Location Standards, Permitted Hazardous Waste Facilities (40 CFR 264.18)	Must not be located within 200 feet of a fault that has been displaced in Holocene time	Not an ARAR. No faults displaced during Holocene.
Wilderness Areas, Wildlife Refuges, Scenic Rivers	Fish and Wildlife Coordination Act (16 U.S.C 661 *et seq.*); Wilderness and Scenic Rivers Act (16 U.S.C. 1274, *et seq.*)	Actions that will impact fish and wildlife must include action to protect affected fish and wildlife resources	No ARARs. No such locations identified onsite or within area impacted by onsite activities
		Designated scenic rivers or river sections must be preserved	
Wetlands, Floodplains	Executive Order 11990; Protection of Wetlands (40 CFR 6 Appendix A); 40 CFR 6.302(a); Oregon Wetland Rules (OAR 141-85)	Must take action to avoid adverse impact, minimize potential harm, and to preserve and enhance wetlands to the extent possible	No onsite wetlands identified, site not within 100-year or 500-year floodplains; therefore, no ARARs result.
	40 CFR 6, Appendix A	Federal agencies shall incorporate floodplain management goals and wetlands protection considerations in its planning, regulatory, and decision-making process	
	40 CFR 6, Appendix A	Federal agencies should avoid new construction in wetlands areas	

Table 3-1
Review of Potential Location-Specific ARARs
Umatilla Depot Activity Explosives Washout Lagoons

Location	Citation	Requirement	Preliminary ARAR designation
Wetlands, Floodplains (continued)	Clean Water Act §404; 40 CFR 230.10; 33 CFR 320-330; ORS 196-.105 *et seq.*; OAR §141-85-005 *et seq.*	Prohibits discharge of dredge or fill material into wetlands without permit	
	Clean Water Act §404(b)(1)	Provides for the enhancement, restoration, or creation of alternate wetlands	
	Location Standards, Permitted Hazardous Waste Facilities (40 CFR 264.18)	Design must prevent washout of hazardous waste	
	Executive Order 11988	Adverse effects associated with the development of a floodplain must be evaluated.	
Critical habitat upon which an endangered or threatened species depends	Endangered Species Act of 1973 (16 U.S.C. 1531 *et seq.*); 50 CFR 402; Fish and Wildlife Coordination Act (16 U.S.C. 661 *et seq.*); ORS 496.004; ORS 496.172 *et seq.*; ORS 498.026; ORS 498.04	Must take action to conserve endangered or threatened species; must not destroy or adversely modify critical habitat	Potential ARAR; critical habitats on UMDA facility, although none identified at Explosives Washout Lagoons.
		Must consult with Department of Interior, FWS, and state personnel required to ascertain that proposed actions will not affect any listed species	

Table 3-1
Review of Potential Location-Specific ARARs
Umatilla Depot Activity Explosives Washout Lagoons

Location	Citation	Requirement	Preliminary ARAR designation
Within area where action may cause irreparable harm, loss, or destruction of significant artifacts	Archaeological and Historic Preservation Act (16 U.S.C. 496a-1)	Must take action to recover and preserve artifacts	Not an ARAR. No artifacts noted at lagoons
Historic project owned or controlled by federal agency	National Historic Preservation Act (16 U.S.C. 470 *et seq.*); 36 CFR 800.1; National Historic Landmarks Program (36 CFR 65); National Register of Historic Places (36 CFR 60)	Must take action to preserve historic properties; planning of action to minimize harm to National Historic Landmarks	Not an ARAR. Historic sites not affected
	Executive Order 11593; 36 CFR 800.4	Federal Agencies must identify possible effects of proposed remedial activities on historic properties, and measures must be implemented to minimize or mitigate potential effects	
Archaeological sites or resources on public land	Archaeological Resources Protection Act of 1979 (16 U.S.C. 470aa-11; 43 CFR 7)	Must take steps to protect resources and to preserve data	Not an ARAR. Archaeological sites not affected.

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within a refuge (ORNL, 1991a), and offsite impacts would not be expected from any of the onsite actions contemplated.

Wetlands and Floodplains. UMDA is not located within 100- or 500-year floodplains, so no ARARs develop in this category (ORNL, 1991a). None of the wetlands identified in the region are located on the UMDA property, so there would be no wetlands ARARs for onsite remediation per se (ORNL, 1991a). Any actions that would affect wetlands adjacent to UMDA would be subject to a number of federal and state ARARs, listed in Table 3-1.

Critical Habitat. The UMDA installation is part of the critical winter range of both the bald eagle (*Haliaeetus leucocephalus*) and the golden eagle (*Aquila chrystaetos*) (Dames & Moore, 1990a). The former is on the federal endangered and threatened species list and both are protected under the Fish and Wildlife Coordination Act (ORNL, 1991a). The peregrine falcon (*Falco peregrinus*), another federally endangered species, has been sighted in the vicinity of UMDA, and the installation is considered part of its critical habitat (Dames & Moore, 1990a). One of three small habitats along the Columbia River where the long-billed curlew (*Numenius Americanus*) still breeds is located on the installation (Dames & Moore, 1990a). The species is on the federal "Candidate" list (Dames & Moore, 1990a). No federal or state threatened or endangered plants have been identified at UMDA (ORNL, 1991a).

Any action that would affect any endangered or threatened species, or adversely impact a species' critical habitat, would be subject to the ARARs outlined in Table 3-1. There are no additional state threatened or endangered species known to inhabit UMDA (ORNL, 1991a).

Artifacts and Historical and Archeological Sites. There are two known historic buildings at UMDA, the headquarters building and the firehouse building (Dames & Moore, 1990a). There are also two potential archeological resources at UMDA that have been tentatively identified, a portion of the Oregon Trail and a prehistoric site (Dames & Moore, 1990a). None of the activities that are contemplated at the Explosives Washout Lagoons will affect these locations, so ARARs are not triggered.

3.1.3 Action-Specific ARARs

The remedial alternative selection process must consider the regulatory requirements associated with each proposed technology. The laws and regulations that were reviewed to identify ARARs are listed in Table 3-2, and selected technologies being considered to remediate the Explosives Washout Lagoons are discussed below with respect to the ARARs so identified. The technologies specifically considered here are capping, excavation, composting, and incineration. More detailed information on the requirements of particular ARARs can be found in ORNL (1991a) and the specific laws and regulations.

Table 3-2
Review of Potential Action-Specific ARARs
Umatilla Depot Activity Explosives Washout Lagoons

Law/Regulation	Preliminary ARAR Designation	Comments
Resource Conservation and Recovery Act (RCRA) EPA Regulations for Hazardous Waste (40 CFR 260 through 270) Oregon Hazardous Waste Management Act Oregon Hazardous Waste Management Regulations (OAR 340-100 through 108)	Not an ARAR; TBC guidance	These rules establish a comprehensive cradle-to-grave program for safe management of hazardous waste. The contaminated soils at the Explosives Washout Lagoons are not RCRA listed wastes, nor do they exhibit the characteristics of reactivity for which explosives wastes are generally designated. However, the contaminated soils are sufficiently similar to hazardous waste that RCRA and state regulations are designated as TBC guidance.
Oregon Solid Waste Regulations (OAR 340-61)	Potential ARAR	These rules establish requirements for the handling, storage, and treatment of solid waste. The contaminated soils and treatment residues are similar to solid waste, so special rules pertaining to incineration (OAR 340-61-045) and composting plants (OAR 340-61-050) are potentially relevant and appropriate.
Oregon Hazardous Waste Facility Siting and Permitting Regulations (OAR 340-120)	Not an ARAR	Do not apply to sites involved in remedial action under the Oregon Environmental Cleanup Law (ORS 465).
Oregon Air Pollution Control Regulations (OAR 340-20)	Potential ARAR	These regulations prescribe treatment and control requirements for potential sources of air contamination. For an incineration-based remediation alternative, these regulations are considered potential ARARs.
Oregon Water Quality Standards (OAR 340-41)	Not an ARAR	These rules set forth Oregon's plans for managing the quality of public waters within the state. No direct or indirect discharges or runoff to public waters are anticipated during this remedial action, so these rules are not considered to be ARARs.

Table 3-2
Review of Potential Action-Specific ARARs
Umatilla Depot Activity Explosives Washout Lagoons

Law/Regulation	Preliminary ARAR Designation	Comments
Oregon Water Pollution Control Regulations (OAR 340-45)	Not an ARAR	These regulations prescribe point source water pollution discharge limitations and associated permitting requirements for both industrial wastewaters and stormwater under the state NPDES program. Because the remedial actions under consideration do not involve point source discharges into waters of the state, these rules are not considered ARARs.
EPA Underground Storage Tank Requirements (40 CFR 280) Oregon Underground Storage Tank Regulations (OAR 340-150)	Not an ARAR	These rules are not considered ARARs because underground storage tanks (USTs) are not present, nor are USTs part of any of the proposed remedial alternatives at the site.
Oregon Recycling and Waste Reduction Regulations (OAR 340-60)	Not an ARAR	These rules establish waste recycling/reduction requirements for municipal solid waste. No conventional municipal solid waste operations are planned at this site.
Oregon Environmental Hazards Notice Regulation (OAR 340-130)	Not an ARAR	These rules are not applicable because they exempt sites already undergoing investigation and cleanup [OAR 340-130-010(2)]. Neither are they relevant and appropriate, since the FS process provides for agency and public notification and involvement.
Oregon Air Toxics Policy (draft--April 15, 1987)	TBC	Because this draft policy has not been formally adopted, it is not considered an ARAR. It is considered a TBC document because it is being uniformly applied by ODEQ to facilities generating significant quantities of certain air toxics. On this basis, several of the constituents of concern in this FS, that are identified as human carcinogens, might require health impact analyses if the proposed remedial action results in significant air emissions.

Note:
TBC = to be considered.

As discussed in Section 3.1.1, the waste from the Explosives Washout Plant is not a RCRA listed waste, nor does the contaminated soil exhibit the characteristic of reactivity that would make federal RCRA and state hazardous waste requirements relevant and appropriate. However, these requirements are pertinent as TBC guidance. Therefore, elements of the federal RCRA requirements for closure of surface impoundments (e.g., lagoons) and requirements for treatment, storage, and disposal (TSD) facilities will be considered.

Capping. Capping involves covering a site to reduce direct exposure to contaminants and to minimize infiltration of precipitation and subsequent vertical migration. Oregon Hazardous Waste Management Regulations are more stringent than federal RCRA requirements with respect to the use of capping for the closure of hazardous waste surface impoundments (e.g., lagoons). Federal RCRA regulations allow closure with waste and contaminated soils either removed (clean closure) or intentionally left in place, while Oregon allows waste or contaminated soil to be left in place only after reasonable efforts have been used to remove the material (OAR 340-104-228). Capping of a hazardous waste site without accompanying efforts to remove contaminated soil would not satisfy the state requirement. The state hazardous waste regulations are TBC criteria rather than ARARs, but the preference for contaminant removal will be considered.

If complete removal of waste and contaminated soil is not possible, the state defers to the design and maintenance requirements for caps contained in 40 CFR 264.228. These include the following:

- Run-on and run-off must be controlled to prevent erosion of or damage to the cap

- The cap must provide long-term minimization of liquid infiltration, and have a permeability less than that of the natural subsoils

- The cap must function with minimal maintenance

- The cap must accommodate settling and subsidence while retaining integrity

- Post-closure monitoring and maintenance must be provided.

Again, these are TBC criteria rather than ARARS, and will be considered only as potential design guidelines.

Capping would probably include grading, construction, and possibly excavation activities that could generate non-point source emissions of particulates and pollutants. Oregon standards for fugitive emissions control are more stringent than the comparable federal

standards under the Clean Air Act, providing limits for total suspended particulates (OAR 340-31-015) and requirements for particulate control (OAR 340-21-050 *et seq.*). The Oregon standards would be ARARs for soil-disturbing activities.

Excavation. Excavation could be used in conjunction with many ex situ treatment and disposal technologies. It is anticipated that contaminated soil would be removed to a depth no greater than groundwater using conventional equipment. As with activities associated with capping, excavation could produce airborne pollutants and particulates. Again, the more stringent non-point source particulate emissions limits and controls specified in Oregon regulations would be ARARs.

Composting. Composting is a biological treatment technology that involves degrading contaminants in piles using microorganisms. Federal RCRA regulations governing the biological treatment of hazardous wastes and the treatment of hazardous wastes in piles are TBC criteria.

The interim status biological treatment standards are found in 40 CFR 265 Subpart Q. They include the following:

- Maintenance of general operating conditions, such as protection from system failure (e.g., use of continuous feed cutoff systems)

- Initial waste analyses and trial tests, and additional analyses and testing whenever the process or incoming waste changes substantially

- Daily inspections for safety and monitoring equipment and weekly inspections for containment

The interim standards for waste piles are found in 40 CFR 265 Subpart L and the final standards in 40 CFR 264 Subpart L. They include the following:

- Protection from wind dispersion

- Initial waste analyses, and additional analyses whenever the type of waste being added to the pile changes substantially

- Containment systems such as an impermeable base, liners, runon control, runoff collection, and holding facilities (when leachate and/or other runoff may develop)

The compost piles would essentially meet these requirements in that they would be separated from the soil by pads and enclosed to protect against precipitation, surface water run-on, and wind dispersal. Water would be added to the compost mixture only to provide sufficient moisture for microbial activity, and no leachate would be

generated. In addition, the compost mixture would be actively managed on at least a weekly basis, and inspected at that time.

The Oregon Solid Waste Management Regulations contain specific rules for composting plants (OAR 340-61-050) that would be relevant to the proposed operation. These include the following:

- Compost utilization plan. Required by ODEQ to assure proper application of composted material.

- Drainage control. Not appropriate, since the compost piles would be protected from run-on and precipitation and would not generate leachate.

- Odor control. Not appropriate, since the facility would be well-removed from sensitive public areas.

- Wastewater discharge. Not appropriate, since no wastewater would be generated.

- Fire protection. Potentially appropriate.

Incineration. Incineration would involve treating soil using an onsite mobile or transportable kiln. Federal RCRA regulations for hazardous waste incinerators are found in 40 CFR 264 Subpart O. Under these regulations, certain exemptions apply to incinerators that destroy waste that is listed solely for reactivity and that contains none of the constituents listed in 40 CFR 261, Appendix VIII. However, the contaminated soil is known to contain 2,4-DNT and 2,6-DNT, both of which are listed in Appendix VIII. Therefore, the RCRA requirements for incinerators are TBC criteria. They include:

- Waste analysis prior to the startup of incineration and periodically thereafter

- Treatment of principal organic hazardous constituents (POHCs) to a destruction removal efficiency (DRE) of 99.99 percent

- Specific stack emissions controls for hydrochloric acid (HCl), particulates, and carbon monoxide (CO)

- Incineration only when operating within design conditions

The Oregon Solid Waste Management Regulations also contain specific rules for solid waste incinerators (OAR 340-61-045). These rules would be relevant to the proposed operation and include the following:

- Air pollution control. All incineration equipment would be required to comply with Oregon air pollution control standards.

- Ash and residue management and disposal plan. Required by ODEQ to assure proper disposal.

- Drainage control around incinerator site. Appropriate.

- Wastewater discharge. Wastewater would be generated by the air scrubbing system and would need to be handled appropriately.

- Fire protection. Appropriate.

The Federal Clean Air Act and Oregon Air Pollution Control Regulations (OAR 340-20) would be applicable to stack emissions resulting from incineration. The requirements are extensive and include providing the highest and best practical treatment of air contaminant emissions, complying with specific emission standards, and providing for monitoring and testing.

3.2 Remedial Action Objectives

Remedial action objectives (RAOs) consist of site-specific goals for protecting human health and the environment. The RAOs should specify the following:

- Preliminary contaminant(s) of concern (identified as TNT, RDX, HMX, 2,4-DNT, TNB, DNB, and NB in Section 3.1.1)
- Media of concern (identified as soil)
- Exposure route(s) and receptor(s) (identified in Section 2.6)
- Acceptable contaminant level or range of levels for each exposure route (i.e., preliminary remediation goals)

The preliminary goals are generally based upon chemical-specific ARARs or health-based standards. They are developed below.

3.2.1 Remedial Action Goals

Neither federal nor state regulations establish chemical-specific soil ARARs for any of the seven contaminants of concern. When chemical-specific ARARs are not available, health-based exposure standards are generally applied.

The NCP specifies that for carcinogens, "acceptable exposure levels are generally concentrations that represent an excess upper bound lifetime cancer risk to an individual of between 1 x 10^{-4} and 1 x 10^{-6}" [40 CFR 300.430(e)(2)(i)(A)(2)]. The NCP further specifies that an excess cancer risk of 1 x 10^{-6} should be used as the point of departure for determining remedial goals. For systemic toxicants, "acceptable exposure levels shall represent concentration levels to which the human population, including sensitive subgroups, may be exposed without adverse affect." [40 CFR 300.430(e)(2)(i)(A)(1)] Adverse effects could occur when the hazard index for a systemic toxicant exceeds 1.0.

Potential risks associated with direct exposure to existing soil contamination at the Explosives Washout Lagoons were summarized in Table 2-8. Both excess cancer risks and noncancerous health effects exceed the NCP acceptable exposure level guidelines by one to three orders of magnitude, depending on the exposure scenario.

Table 2-9 summarized the concentrations of the individual contaminants of concern associated with various carcinogenic and non-carcinogenic human risk levels, as calculated in multiple pathway exposure evaluations (Dames & Moore, 1991). The information from that table was compared to the analytical data developed by MKES/CH2M HILL (1992) and Weston (Dames & Moore, 1991) from samples collected within the lagoons. The following observations were made:

- *TNT*, a potential human carcinogen, was frequently detected in near-surface soils in concentrations equivalent to an excess cancer risk greater

than 1×10^{-4} for exposure under both the residential and light industrial use scenarios.

- *RDX*, a potential human carcinogen, was frequently detected in near-surface soils in concentrations equivalent to an excess cancer risk greater than 1×10^{-4} for exposure under the residential use scenario, and 1×10^{-5} to 1×10^{-4} under the light industrial use scenario.

- *HMX*, a systemic toxicant not classified as a carcinogen, was never detected at concentrations exceeding a hazard index of 1.0 for either the residential land use scenario or the light industrial use scenario. The hazard index associated with detected concentrations was usually two to three orders of magnitude less than 1.0.

- *2,4-DNT*, a probable human carcinogen, was frequently detected in deeper soils (more than 8 feet below the lagoons) at concentrations equivalent to an excess cancer risk of 1×10^{-6} to 9.6×10^{-5} for exposure under the residential and industrial use scenarios.

- *TNB*, a systemic toxicant not classified as a carcinogen, was detected throughout the soil column at concentrations from 2 to 47 µg/g. A concentration of 47 ppm is equivalent to a hazard index of 7 (industrial use scenario) and 48 (residential use scenario).

- *DNB*, a systemic toxicant not classified as a carcinogen, was never detected at concentrations exceeding a hazard index of 1.0 under either future use scenario.

- *NB*, a systemic toxicant not classified as a carcinogen, was never detected at concentrations exceeding a hazard index of 1.0 under either future use scenario. The hazard index associated with detected concentrations was generally one to two orders of magnitude less than 1.0.

The NT, RDX, and 2,4-DNT contribute to a total excess cancer risk that exceeds the NCP remedial action criterion of 1 x 10^{-4}. TNT and RDX are present in the highest concentrations and quantities. In addition, TNT and RDX dominate the cancer risk associated with the near-surface soils most likely to result in human exposure. 2,4-DNT is present in much lower concentrations and total quantities; it becomes a factor in the total cancer risk only at 10 to 15 feet below the lagoons. Even then, concentrations of 2,4-DNT are only 1 to 5 ppm, with the exception of a concentration of 16 µg/g observed at a depth of 15 to 16.5 feet below the western end of the south lagoon.

The hazard index calculated for TNB consistently exceeds the acceptable hazard index of 1.0, ranging from 2 to 48 (residential use scenario) and <0.1 to 7 (industrial use scenario). However, because of the paucity of toxicity data for TNB, the calculated hazard index includes an uncertainty factor of 10,000 (Dames & Moore, 1991) ,

reflecting a very high degree of conservatism. This uncertainty results in part from the fact that a default dermal absorption factor was used (Dames & Moore, 1991). Given the fact that the uncertainty factor is three orders of magnitude greater than the calculated hazard index, it is difficult to draw meaningful conclusions from the hazard index. Therefore, TNB is not considered in setting primary remedial goals. However, TNB will be considered in establishing a cleanup-to-background scenario. USATHAMA plans to conduct further toxicity testing to reduce the uncertainty associated with the TNB hazard index calculations.

The hazard indexes of HMX, DNB, and NB in samples collected to date have never exceeded 1.0 and are on average well below 1.0. Therefore, these contaminants were not considered further in establishing remedial goals.

The following RAOs are based on the information presented above, CERCLA requirements, Army safety guidelines, and federal and state ARARs:

- Remove soil containing potentially reactive concentrations of explosives (greater than or equal to 10 weight percent), or otherwise protect it from conditions that could induce reaction.

- Reduce to 1×10^{-6} (the NCP point of departure) the total excess cancer risk in soil to which human exposure is likely, if feasible. It is assumed

that this level would approximate background, which is the State of Oregon's point of departure.

- If 1×10^{-6} is not feasible, reduce excess cancer risks to the lowest feasible level within the range of 1×10^{-4} to 1×10^{-6}, the final level to be determined based on a cost-benefit analysis.

These RAOs were used to determine a range of soil volumes and treatment standards to be considered for remediation.

3.2.2 Volume to be Remediated

Determining the volume of soil to be remediated depends on the contaminant concentrations and the likelihood of human exposure at varying soil depths. To aid this evaluation, Table 3-3 presents excess cancer risk as a function of sampling depth for each of the four borings completed directly below the lagoons (MKES/CH2M HILL, 1992). This is shown graphically in Figure 3-1. This table assumes the same direct exposure scenarios for all samples, regardless of depth. This is a conservative assumption in that direct exposure to subsurface soil is less likely to occur than exposure to surface soil. The percent contaminant recovery versus depth for TNT, RDX, and 2,4-DNT is presented in Table 3-4.

TABLE 3-3
EXCESS CANCER RISK VERSUS SAMPLING DEPTH(1)
BOREHOLE 5

Page 1 of 4

	TNT		RDX		2,4-DNT(4)		TOTAL(2)	
Depth(3)	Residential	Industrial	Residential	Industrial	Residential	Industrial	Residential	Industrial
0-2	9.1E-07	4.3E-07	3.2E-05	6.1E-06	2.5E-06	1.1E-06	3.6E-05	7.6E-06
2-3.5	3.7E-07	1.7E-07	1.8E-05	3.3E-06	2.5E-06	1.1E-06	2.1E-05	4.7E-06
4-5.5	1.1E-07	5.4E-08	9.7E-07	1.8E-07	2.5E-06	1.1E-06	3.6E-06	1.4E-06
6-7.5	1.1E-07	5.4E-08	1.8E-06	3.4E-07	2.5E-06	1.1E-06	4.4E-06	1.5E-06
8-9.5	7.5E-07	3.6E-07	2.7E-06	5.1E-07	5.4E-06	2.5E-06	8.8E-06	3.3E-06
10-11.5	2.2E-06	1.1E-06	3.1E-06	5.8E-07	2.6E-05	1.2E-05	3.1E-05	1.4E-05
15-16.5	3.0E-06	1.4E-06	3.5E-06	6.7E-07	2.4E-05	1.1E-05	3.1E-05	1.3E-05
20-21.5	2.5E-06	1.2E-06	3.4E-06	6.5E-07	2.5E-06	1.1E-06	8.4E-06	3.0E-06
25-26.5	3.2E-06	1.5E-06	5.3E-06	1.0E-06	2.5E-06	1.1E-06	1.1E-05	3.7E-06
30-31.5	1.4E-06	6.7E-07	3.0E-06	5.5E-07	2.5E-06	1.1E-06	6.9E-06	2.4E-06
30-31.5	1.8E-06	8.4E-07	3.3E-06	6.2E-07	1.4E-05	6.5E-06	1.9E-05	7.9E-06
35-36.5	2.9E-06	1.4E-06	5.0E-06	9.4E-07	2.5E-06	1.1E-06	1.0E-05	3.5E-06
40-41.5	3.8E-06	1.8E-06	5.3E-06	1.0E-06	2.5E-06	1.1E-06	1.2E-05	3.9E-06
45-46.5	6.0E-06	2.9E-06	5.7E-07	1.1E-07	2.5E-06	1.1E-06	9.1E-06	4.1E-06
50-51.5	2.5E-06	1.2E-06	4.4E-07	8.3E-08	2.5E-06	1.1E-06	5.5E-06	2.4E-06

(1) Pathways consist of ingestion of, inhalation of, and dermal contact with soil; risk calculations based on concentrations detected during November 1991 soil investigation.

(2) Summation of risks from TNT, RDX, and 2,4-DNT. For concentrations below the detection limit, the risk associated with the detection limit was included in the summation.

(3) Depth in feet below the bottom of the lagoon.

(4) The detection limit of 0.424 ug/g exceeded the 1.0E-06 risk level for both the residential and the industrial use scenarios.

TABLE 3-3
EXCESS CANCER RISK VERSUS SAMPLING DEPTH(1)
BOREHOLE 6

	TNT		RDX		2,4-DNT(4)		TOTAL(2)	
Depth(3)	Residential	Industrial	Residential	Industrial	Residential	Industrial	Residential	Industrial
0-2	1.3E-04	6.2E-05	2.3E-04	4.2E-05	2.5E-06	1.1E-06	3.6E-04	1.1E-04
2-3.5	1.9E-04	9.3E-05	2.4E-04	4.5E-05	2.5E-06	1.1E-06	4.4E-04	1.4E-04
2-3.5	2.4E-04	1.2E-04	3.1E-04	5.8E-05	2.5E-06	1.1E-06	5.5E-04	1.8E-04
4-5.5	2.8E-07	1.3E-07	2.4E-05	4.5E-06	2.5E-06	1.1E-06	2.7E-05	5.8E-06
6-7.5	1.1E-07	5.4E-08	2.3E-06	4.3E-07	4.3E-06	2.0E-06	6.7E-06	2.4E-06
8-9.5	1.1E-07	5.4E-08	1.4E-06	2.6E-07	2.5E-06	1.1E-06	4.0E-06	1.5E-06
10-11.5	1.1E-07	5.4E-08	7.7E-07	1.4E-07	2.5E-06	1.1E-06	3.4E-06	1.3E-06
15-16.5	3.5E-06	1.7E-06	1.6E-06	3.1E-07	2.5E-06	1.1E-06	7.6E-06	3.1E-06
20-21.5	1.6E-06	7.8E-07	2.2E-06	4.1E-07	2.5E-06	1.1E-06	6.3E-06	2.3E-06
25-26.5	1.7E-06	8.3E-07	1.1E-06	2.0E-07	2.5E-06	1.1E-06	5.3E-06	2.2E-06
30-31.5	1.9E-06	9.1E-07	1.5E-06	2.7E-07	4.5E-06	2.1E-06	7.9E-06	3.2E-06
35-36.5	2.2E-06	1.0E-06	3.7E-06	7.0E-07	8.8E-06	4.0E-06	1.5E-05	5.8E-06
40-41.5	3.3E-06	1.6E-06	5.0E-06	9.4E-07	1.5E-05	7.1E-06	2.4E-05	9.6E-06
45-46.5	3.5E-06	1.7E-06	9.8E-07	1.8E-07	1.0E-05	4.6E-06	1.5E-05	6.5E-06
50-51.5	6.7E-06	3.2E-06	8.3E-07	1.6E-07	1.5E-05	6.7E-06	2.2E-05	1.0E-05

(1) Pathways consist of ingestion of, inhalation of, and dermal contact with soil; risk calculations based on concentrations detected during November 1991 soil investigation.
(2) Summation of risks from TNT, RDX, and 2,4-DNT. For concentrations below the detection limit, the risk associated with the detection limit was included in the summation.
(3) Depth in feet below the bottom of the lagoon.
(4) The detection limit of 0.424 ug/g exceeded the 1.0E-06 risk level for both the residential and the industrial use scenarios.

TABLE 3-3
EXCESS CANCER RISK VERSUS SAMPLING DEPTH(1)
BOREHOLE 7

	TNT		RDX		2,4-DNT(4)		TOTAL(2)	
Depth(3)	Residential	Industrial	Residential	Industrial	Residential	Industrial	Residential	Industrial
0-2	3.5E-04	1.7E-04	5.5E-07	1.0E-07	2.5E-06	1.1E-06	3.5E-04	1.7E-04
2-3.5	3.2E-04	1.5E-04	2.0E-06	3.8E-07	2.5E-06	1.1E-06	3.3E-04	1.6E-04
4-5.5	2.0E-07	9.5E-08	9.5E-06	1.8E-06	2.5E-06	1.1E-06	1.2E-05	3.0E-06
6-7.5	2.6E-07	1.2E-07	5.8E-06	1.1E-06	4.0E-06	1.8E-06	1.0E-05	3.1E-06
8-9.5	3.5E-07	1.7E-07	4.5E-07	8.4E-08	3.6E-06	1.7E-06	4.4E-06	1.9E-06
10-11.5	1.1E-06	5.0E-07	4.5E-06	8.5E-07	1.6E-05	7.2E-06	2.1E-05	8.5E-06
15-16.5	8.5E-06	4.0E-06	1.3E-05	2.4E-06	9.5E-05	4.4E-05	1.2E-04	5.0E-05
20-21.5	1.1E-06	5.2E-07	1.5E-05	2.8E-06	1.8E-05	8.2E-06	3.4E-05	1.2E-05
25-26.5	2.9E-06	1.4E-06	4.8E-06	9.1E-07	1.7E-05	7.9E-06	2.5E-05	1.0E-05
30-31.5	5.0E-06	2.4E-06	1.0E-05	2.0E-06	2.3E-05	1.1E-05	3.9E-05	1.5E-05
35-36.5	5.4E-07	2.6E-07	1.6E-06	2.9E-07	7.1E-06	3.3E-06	9.2E-06	3.8E-06
40-41.5	1.1E-06	5.4E-07	2.0E-06	3.8E-07	1.4E-05	6.3E-06	1.7E-05	7.3E-06
45-46.5	6.0E-06	2.9E-06	4.7E-07	8.8E-08	2.0E-05	9.4E-06	2.7E-05	1.2E-05
45-46.5	6.7E-06	3.2E-06	5.2E-07	9.8E-08	2.6E-05	1.2E-05	3.3E-05	1.5E-05

(1) Pathways consist of ingestion of, inhalation of, and dermal contact with soil; risk calculations based on concentrations detected during November 1991 soil investigation.
(2) Summation of risks from TNT, RDX, and 2,4-DNT. For concentrations below the detection limit, the risk associated with the detection limit was included in the summation.
(3) Depth in feet below the bottom of the lagoon.
(4) The detection limit of 0.424 ug/g exceeded the 1.0E-06 risk level for both the residential and the industrial use scenarios.

TABLE 3-3
EXCESS CANCER RISK VERSUS SAMPLING DEPTH(1)
BOREHOLE 8

	TNT		RDX		2,4-DNT(4)		TOTAL(2)	
Depth(3)	Residential	Industrial	Residential	Industrial	Residential	Industrial	Residential	Industrial
0-2	1.8E-04	8.8E-05	2.2E-06	4.1E-07	2.5E-06	1.1E-06	1.9E-04	9.0E-05
2-3.5	3.5E-06	1.7E-06	2.8E-07	5.2E-08	2.5E-06	1.1E-06	6.2E-06	2.9E-06
4-5.5	4.9E-06	2.3E-06	9.5E-08	1.8E-08	2.5E-06	1.1E-06	7.5E-06	3.5E-06
6-7.5	5.0E-07	2.4E-07	2.7E-07	5.1E-08	2.5E-06	1.1E-06	3.3E-06	1.4E-06
8-9.5	1.5E-07	7.3E-08	9.5E-08	1.8E-08	2.5E-06	1.1E-06	2.7E-06	1.2E-06
10-11.5	2.0E-06	9.6E-07	3.4E-07	6.5E-08	1.3E-05	5.9E-06	1.5E-05	6.9E-06
15-16.5	2.0E-06	9.3E-07	1.8E-06	3.3E-07	1.5E-05	6.8E-06	1.8E-05	8.0E-06
15-16.5	1.8E-06	8.5E-07	1.8E-06	3.4E-07	1.5E-05	6.9E-06	1.9E-05	8.1E-06
20-21.5	2.9E-06	1.4E-06	2.5E-06	4.6E-07	2.5E-05	1.2E-05	3.1E-05	1.3E-05
25-26.5	6.3E-06	3.0E-06	4.7E-06	8.8E-07	4.1E-05	1.9E-05	5.2E-05	2.3E-05
30-31.5	1.9E-06	9.1E-07	1.2E-06	2.2E-07	1.5E-05	7.1E-06	1.9E-05	8.2E-06
35-36.5	7.3E-06	3.5E-06	1.8E-06	3.5E-07	2.2E-05	1.0E-05	3.1E-05	1.4E-05
40-41.5	9.5E-06	4.5E-06	3.7E-06	7.0E-07	2.6E-05	1.2E-05	3.9E-05	1.7E-05
45-46.5	4.9E-06	2.3E-06	6.3E-07	1.2E-07	2.0E-05	9.1E-06	2.5E-05	1.2E-05
50-51.5	3.8E-06	1.8E-06	9.5E-08	1.8E-08	1.3E-05	6.2E-06	1.7E-05	8.0E-06

(1) Pathways consist of ingestion of, inhalation of, and dermal contact with soil; risk calculations based on concentrations detected during November 1991 soil investigation.
(2) Summation of risks from TNT, RDX, and 2,4-DNT. For concentrations below the detection limit, the risk associated with the detection limit was included in the summation.
(3) Depth in feet below the bottom of the lagoon.
(4) The detection limit of 0.424 ug/g exceeded the 1.0E-06 risk level for both the residential and the industrial use scenarios.

Table 3-4
Percent Contaminant Removal Versus Excavation Depth[a]

Depth (ft)	Depth from Ground Level (ft)	TNT (%)	RDX (%)	2,4-DNT (%)
0	6	0	20	0.0
2	8	93	57	0.0
4	10	97	61	0.0
6	12	97	63	0.0
8	14	97	63	2.0
10	16	97	66	10
15	21	97	72	22
20	26	97	80	32
25	31	97	85	43
30	36	98	90	54
35	41	98	94	66
40	46	99	99	78
45	51	99	99	89
50	56	100.0	100.0	100.0

[a]Calculated based on the area under the curve defined by a graph of contaminant concentration versus depth. Average concentrations derived from samples collected during 1989 and 1991 sampling events within lagoons.

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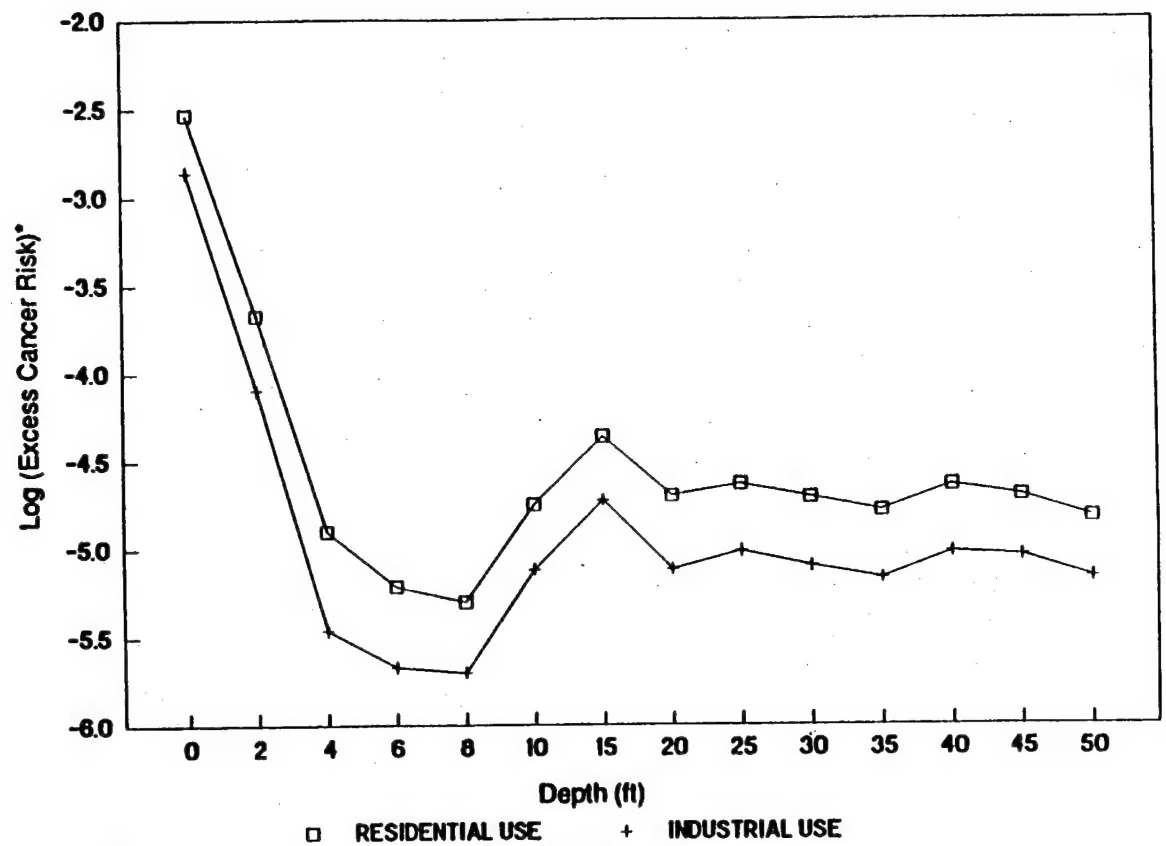

* NOTE: Excess cancer risk was calculated based on average soil concentrations of TNT, RDX, and 2,4-DNT observed at each depth.

Figure 3-1
Excess Cancer Risk as a Function of Depth Below Bottom of Explosives Washout Lagoons

Four potential excavation depths were selected for evaluation based on these tables and the RAOs: 2 feet below the lagoons, 5 feet below the lagoons, 20 feet below the lagoons, and 47 feet below the lagoons (the approximate depth to groundwater). The selection of these depths is discussed below.

Excavation to 47 Feet. Contaminants have been detected throughout the soil column to the groundwater, and in concentrations with an associated excess cancer risk of greater than 1 x 10^{-6}. Therefore, an excavation to groundwater would be required to reduce the excess cancer risk to 1 x 10^{-6}, the point of departure stipulated by the NCP. Such an excavation would also be an approximation of the state's "cleanup to background" scenario.

Excavation to 5 Feet. Figure 3-1 and the data in Tables 3-3 and 3-4 were evaluated to determine whether there were one or more excavation depths in addition to groundwater that would achieve acceptable levels of protection and a well-defined net benefit in terms of risk reduction. Of particular interest were any depths at which distinct inflections in contaminant concentration trends, excess cancer risk trends, and the rate of contaminant removal are observed.

One alternate excavation depth suggested by the data lies approximately 4 to 5.5 feet below the lagoons. The excess cancer risk (residential use scenario) typically approaches and exceeds 1 x 10^{-4} (as high as 1 x 10^{-2}) in samples collected between the surface and a depth of 3.5 feet. In the sampling interval from 4 to 5.5 feet, the excess

cancer risk (residential use scenario) generally decreases to a range of 1×10^{-6} to 2×10^{-5}. There appears to be no further consistent decline in contaminant concentrations and associated excess cancer risks below this depth. The risks associated with contaminant concentrations observed at depths of 10 feet, 20 feet, 30 feet, and 40 feet below the lagoons are approximately the same as those at 5 feet, so a further reduction in residual risk would not be achieved by deeper excavations.

At the same time, an excavation to an average depth of 5 feet removes approximately 97 percent of the total TNT in the soil and 63 percent of the RDX. (As noted in Section 3.1.1, TNT presents 90 percent of the noncarcinogenic risk to human health from soil contamination, and TNT and RDX together present 97 percent of the carcinogenic risk.) While additional quantities of contaminants are removed by deeper excavations, the rate of contaminant removal below 5 feet flattens considerably. For example, an excavation to a depth of 10 feet removes only an additional 0.1 percent of the total TNT and 3 percent of the total RDX.

Since the excess cancer risks at a depth of 4 to 5.5 feet and below are generally within the range of EPA's acceptable cancer risks and since this depth presents a distinct point at which the greatest degree of risk reduction and contaminant removal occurs, an excavation with an average depth of 5 feet below the lagoons was selected for evaluation. This scenario does not preclude varying the excavation depth around the lagoons; actual excavation depths at any given location would be based on reducing the excess cancer risk in the soil below the excavation to the range of about 1×10^{-6} to

1×10^{-5} (residential use scenario). For example, an excess cancer risk of 1.2×10^{-4} (residential use scenario) is observed at a depth of 15 to 16.5 feet in the western end of the south lagoon, so a deeper excavation might be indicated there if human exposure at that depth is likely.

Excavation to 2 Feet. Total explosives concentrations in samples collected from the bottoms and sidewalls of the lagoons frequently range from 0.1 to 9 weight percent. Total explosives concentrations of 10 weight percent or greater are considered potentially reactive. Excavating the 2 feet of soil immediately below the lagoons, plus the sidewalls and berms, would minimize the possibility that soil containing potentially reactive explosives concentrations remains at the lagoons.

Excavation to 20 Feet. Future soil-disturbing activities (e.g., trenching, building construction) and associated human exposure are unlikely to occur at soil depths greater than 20 feet below the lagoons. Therefore, an excavation to that depth of all soils in the lagoons area regardless of contaminant concentrations is considered.

Lateral Extent of Excavation. For purposes of estimating volumes for the 2-foot, 5-foot, and 20-foot excavations, it is assumed that the excavation would project down vertically from the perimeter of the lagoons, removing all soil directly beneath the lagoons to the specified depth. Thus, the bottom dimensions of the excavation would be the same as the current surface dimensions of the lagoons. The sidewalls of the excavation are then assumed to be sloped back from the bottom at a ratio of

1.5 horizontal to 1.0 vertical. This would effectively remove the central and perimeter berms enclosing the lagoons, and provide sufficient excavation stability to preclude the need for special construction techniques (e.g., shoring) during excavation.

For the excavation to groundwater, the lateral extent of the excavation is assumed to be based on soil boring data collected outside the lagoon, assuming a cleanup-to-background. On the northeast side, the excavation is assumed to extend to 10 feet beyond the bottom of the north lagoon. On the other three sides, the excavation is assumed to extend to 20 feet beyond the bottom of the lagoons. Vertical sidewalls are assumed, in order to minimize the volume of uncontaminated soil removal and because of topographic constraints that preclude substantial sideslopes. Again, it is assumed that the central and perimeter berms would be removed.

The proposed excavation profiles are shown in Figure 3-2. The associated volumes and masses are provided in Table 3-5.

3.2.3 Soil Treatment Standards

As discussed in Section 3.1.1, neither federal nor state regulations specify treatment standards for the explosives of concern. Given that, the NCP requires a risk-based assessment of treatment standards, with the point of departure being an excess cancer risk of 1×10^{-6}. The State of Oregon requires an assessment of treatment to background (for practical purposes, below detection limits) or to the lowest concentration

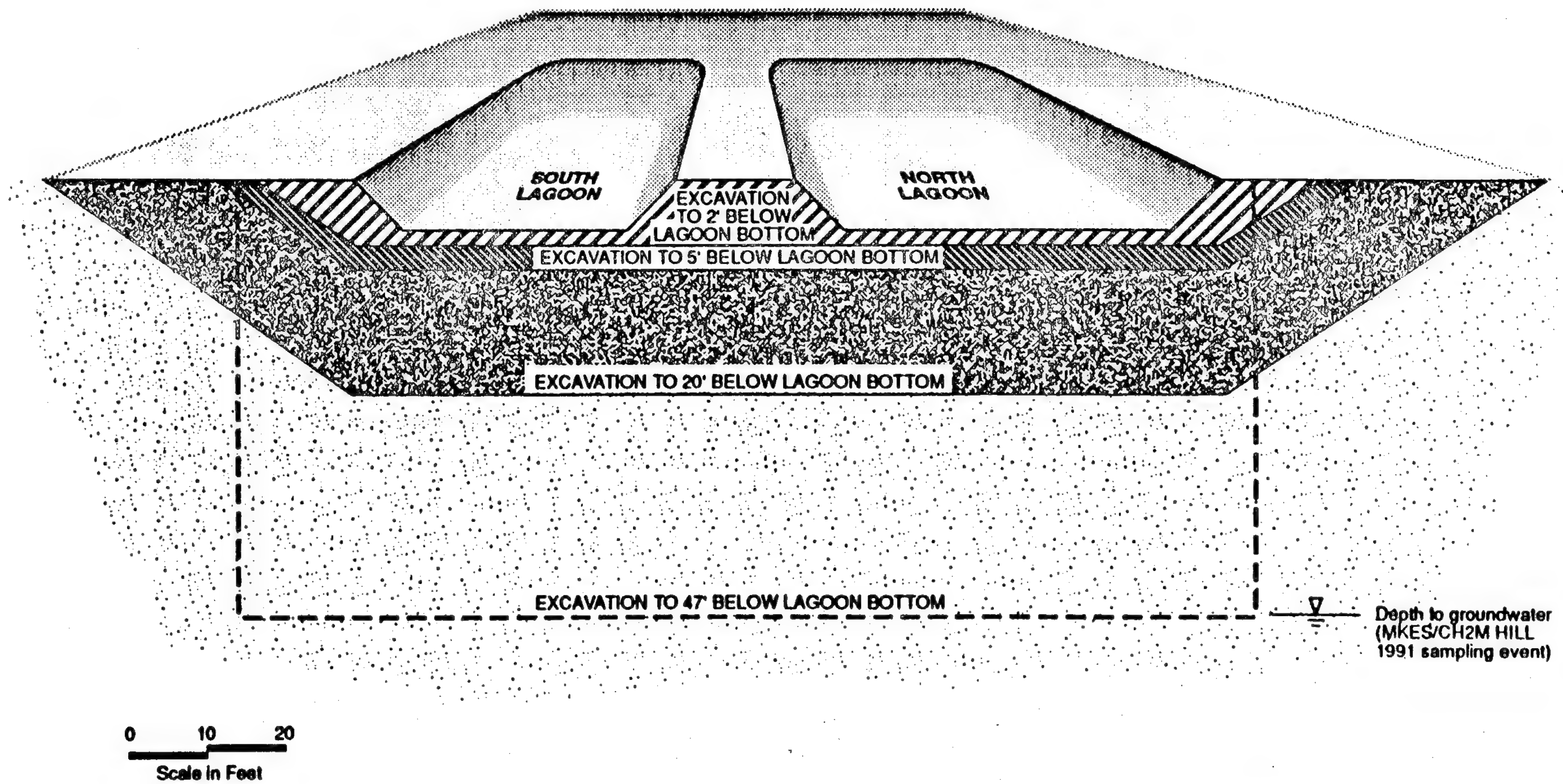

Figure 3-2
Typical Cross Sections for Excavation Options

level that is feasible, protective of human health and the environment, and cost effective.

Table 3-5
Excavation Volume and Mass as a Function of Depth

Depth Below Bottom of Lagoons (ft)	Depth Below Ground Surface (ft)	In-Place Volume to be Excavated (cy)	Excavated Volume[a] (cy)	Weight[b] (tons)
2	8	2,100	2,500	3,700
5[c]	11	3,900	4,780	6,800
20	26	17,000	21,000	30,000
47	53	27,000	32,000	47,000

cy = cubic yards
[a]Loose volumes; assumes a 20 percent bulking factor incurred during excavation.
[b]Assumes a unit weight of soil prior to excavation of 1.75 tons/cy.
[c]Assumes an average depth of 5 feet. Actual excavation depths throughout lagoons may vary, depending on contaminant concentrations.

3.3 General Response Actions

This section describes broad categories of remedial measures, called general response actions, that could be used to achieve the RAOs discussed in Section 3.2. A particular general response action might be accomplished by any of several technology types. In

turn, a single technology type might encompass several more specific methodologies called process options. For example, "treatment" would be a general response action, "chemical treatment" would be a technology type, and solvent extraction and oxidation would be two examples of process options.

The following general response actions considered alone or in combination and when implemented by appropriate technologies could potentially achieve the RAOs:

- No Action
- Institutional Control
- Containment
- Removal
- Immobilization
- Treatment

The NCP requires that "No Action" be included among the general response actions evaluated in every FS [40 CFR 300.430(e)(6)]. No Action means that no response to contamination is made, activities previously initiated are abandoned, and no further active human intervention occurs. However, natural recovery of contaminated media might occur. The No Action response provides a baseline for comparison to the other remedial response actions.

Institutional controls include measures such as land use restrictions (achieved through zoning and deed restrictions), site access restrictions, and relocation of receptors. Although potential exposure can be reduced by these means, the contaminated media are not directly remediated. As with the No Action scenario, natural recovery of contaminated media might occur.

Containment technologies control or reduce migration of the hazardous substances into the surrounding environment. They also might isolate the contaminated media to reduce the possibility of exposure by direct contact. Typically, these actions involve use of a physical barrier to block a contaminant migration pathway.

Removal technologies involve moving the waste or contaminated material from its location at the site to another location either onsite or offsite for storage, treatment, or disposal. Although removal by itself can disrupt the exposure pathway(s), it has little or no effect on the toxicity or volume of the contaminated material. In fact, removal might temporarily increase exposure by increasing the mobility of the contaminants (e.g., production and dispersion of contaminated dust during excavation). Removal is often specified in conjunction with treatment.

Immobilization is a general response action comprised of technologies that limit the solubility or mobility of contaminants. Immobilization might or might not involve a change in the physical characteristics of the matrix containing the waste. Immobilization can involve physical/chemical processes that do more than simply entrap the

contaminants. Solidification alone without physical/chemical stabilization of contaminants within the solidified structure is not considered a treatment under CERCLA (EPA, 1991a).

Technologies that permanently and significantly reduce the toxicity, mobility, or volume of wastes make up the treatment general response action. In some cases, treatment technologies are used to change the properties of the waste so that it can undergo further treatment. Although treatment technologies can change the nature of the wastes or contaminated materials, there are usually residual materials or byproducts that must be disposed of with or without further treatment. The residuals and byproducts might or might not be hazardous.

A final remedial action might combine several response actions, technologies, or process options.

3.4 Identification and Screening of Technologies

In this section, the technologies associated with the general response actions discussed in Section 3.3 and typical process options for each technology are identified, and the results of the technology screening evaluation are presented. The screening was intended to eliminate inappropriate remedial action options. The rationale for rejecting

certain process options or whole technologies is presented here. Process options selected for further detailed evaluation are described in Section 3.5.

A two-step screening process was used. The initial screening reviewed technical and regulatory implementability to eliminate clearly inappropriate options. Those candidate technologies that survived the initial screening were screened in greater detail based on consideration of the following three general criteria:

- Effectiveness
- Implementability
- Cost

As stipulated by EPA, the cost criterion played a limited role in the screening of technologies and process options (EPA, 1988b). Greater emphasis was placed on effectiveness and implementability, so that clearly effective and implementable remedial technologies were retained for further detailed analysis. Only relative capital and operating and maintenance costs were considered, with evaluations made on the basis of engineering judgment. The detailed analysis develops remedial costs in greater depth so as to provide guidance for the effective development of a ROD.

3.4.1 Screening Factors

Factors affecting screening decisions fall into four groups:

- Waste Characteristics
- Site Characteristics
- Technology Characteristics
- Regulatory Preferences

3.4.1.1 Waste Characteristics

The identification, quantification, and characterization of the contaminants present at a site form the logical and necessary basis to study the feasibility of a remedial action. Characteristics influencing selection of remedial options for the Explosives Washout Lagoons' soils include:

- Reactivity. The maximum concentration of explosives measured to date in any sample of lagoon soils is 8.9 percent, which is below the concentration at which an explosive reaction would occur. Concentrations greater than or equal to 12 percent by weight are the minimum required for detonation (Arthur D. Little, Inc., 1987), although USATHAMA uses 10 percent as a conservative guideline. Military regulations and prudence dictate, however, that technologies considered for remediation mitigate the possibility of a detonation.

- Volatility. As shown in Table 2-3, the explosives contaminants have a relatively low vapor pressure at ambient temperatures.

- Aqueous Phase Solubility. As shown in Table 2-3, the explosive contaminants found on site are relatively insoluble in water.

- Solubility in Other Solvents. The explosives considered here are readily solubilized in many organic solvents.

- Soil Volume Requiring Remediation. The total soil volume to be remediated affects the choice of an appropriate remediation technology. As discussed in Section 3.2, the soil volumes under consideration range from 2,500 cy to 32,000 cy (3,700 tons to 47,000 tons) as excavated.

3.4.1.2 Site Characteristics

Site characteristics that influence remedy selection include:

- Location and Accessibility. UMDA is located in a rural setting. The lagoons are located near the center of the installation, at least 1 mile from the nearest exterior fence. Paved roads provide access to within about 1/2 mile of the lagoons, and gravel roads cover the remaining distance. Space limitations around the lagoons include the escarpment, which rises immediately to the southeast, and munitions storage igloos located about 1/2 mile to the west and northwest. It would be desirable

to retain open access to the area south of the lagoons to facilitate future groundwater activities.

- Security. UMDA is fenced and guarded 24 hours a day. It is expected to retain its status as a restricted-access military installation at least through the 1990s.

- Proximity to Potential Receptors. Military personnel assigned to UMDA are the only reasonable nearby receptors at this time because of the limited access and distance from civilian populations.

- Resource Availability. An electrical transformer has been installed at the lagoons and is available for tie-in. Water can be supplied from the installation hydrant system, access to which is located uphill from the lagoons. However, the substantial irrigation needs of the region combined with the semi-arid climate limit the acceptability of remedial actions that would require large water volumes. The site does not have natural gas service. Lined evaporation basins located at UMDA are available to dispose of wastewater; the ponds were originally constructed to contain well purge water and decontamination water from the groundwater monitoring program.

- Surface Conditions. The lagoons and associated berms are devoid of vegetation. The area surrounding the lagoons is covered by grasses and low brush.

- Geology. A description of the site geology is given in Chapter 2. In general, the soil consists of fine to coarse sands and gravels with occasional silt lenses. The groundwater table elevation varies seasonally; during the November 1991 sampling event, groundwater was encountered about 47 feet below the bottom of the lagoons.

3.4.1.3 Technology Characteristics

The primary influencing characteristic of a technology is its ability to achieve the remedial action objectives. In addition, the following characteristics influence remedy selection.

- In Situ Versus Ex Situ. In situ treatment provides the advantage of minimizing exposure during remediation. However, in situ technologies are limited by the need to be able to perform the treatment uniformly throughout the soil mass and provide evidence of the completeness of the remediation. The ability to accomplish this is highly dependent on geology, hydrology, soil characteristics, and waste characteristic of the

site. Generally, the effectiveness of in situ remedial technologies has not been studied or demonstrated for explosives-contaminated soils.

- Onsite Versus Offsite Treatment. There are advantages and disadvantages to both onsite and offsite remediation. The NCP specifies a preference for onsite remedies. Onsite remediation eliminates the need to apply for and obtain local, state, and federal permits, although it does not preclude meeting the substantive requirements of the permit regulations. The waste generator retains greater control of the waste and residues. Costs of transportation are minimized, and costs for onsite treatment will generally be lower if there is a sufficient waste volume. Conversely, onsite treatment costs will generally be higher if the volume of waste to treat is small because of the fixed costs required to mobilize a treatment system onsite.

  Offsite treatment and disposal relieves the waste generator of the responsibility for meeting the substantive requirements for waste treatment and disposal facilities. However, costs will generally be higher. In addition, the generator retains future liability for wastes treated offsite and the resulting residues, without retaining control over their disposition. Finally, offsite treatment increases short-term risks because of the potential for public exposure and environmental damage in the event of a transportation accident.

3.4.1.4 Regulatory Preferences

Section 121 (b) of CERCLA mandates that, where possible, EPA select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable." Remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants as a principal element" are preferred. This regulatory requirement influences the selection of applicable remedial technologies and must be factored into technology screening decisions.

3.4.2 Results of Initial Screening

Figure 3-3 shows the general response actions presented in Section 3.3 as well as possible technologies and process options. The technologies and process options shown were selected on the basis of previous experience. The results of the initial screening are shown in the figure by shading those technologies and process options that do not warrant further evaluation. Comments summarizing the reason for rejection are provided in the rightmost column.

Technologies and process options were initially screened by assessing whether or not they were conceptually viable with respect to technical capabilities and regulatory preferences. A brief discussion of the important parameters and rationale behind particular screening decisions follows.

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
NO ACTION	NONE	NOT APPLICABLE	No actions are taken to meet remedial objectives.	Detailed evaluation required by NCP.
INSTITUTIONAL CONTROLS	ACCESS RESTRICTION	FENCE/WARNING SIGNS	Fence site perimeter and post warning signs.	Inconsistent with regulatory agency preference for unrestricted use.
		DEED/ZONING RESTRICTIONS	Restrict site use through legally binding requirements on property; deed & zoning restrictions.	Inconsistent with regulatory agency preference for unrestricted use.
	MONITORING	GROUNDWATER	Test groundwater for contaminant levels.	Applicable for monitoring effectiveness of remedy. Not a remedy itself.
		AIR	Test air for volatile contaminant levels and particulates.	Applicable for monitoring dust and contaminant control during excavation. Not a remedy itself.
		SOIL	Test soil for contaminant levels.	Applicable for monitoring effectiveness, especially during excavation. Not a remedy itself.

Eliminated from further consideration

Figure 3-3
Initial Screening of Technologies and Process Options for Soil (page 1 of 4)

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
CONTAINMENT	COVER	SOIL COVER	Layer of clean soil; intended to minimize contact with residual contamination.	Provides some protection against exposure; does not reduce toxicity or volume. Some reduction in mobility.
		REVEGETATION	Plant grass or other vegetation to minimize soil dispersion.	Does not reduce toxicity or volume. Native vegetation provides minimal stabilization of soil. Desirable for restoration of site.
		ENGINEERED CAP	Single or multilayered cap of various materials with/without impermeable membrane. Designed to reduce infiltration.	Reduces mobility and exposure. No reduction in toxicity or volume. Restricts future use.
	SURFACE CONTROL	WATER SPRAYING	Periodically wet exposed soils to prevent generation of dust.	Applicable during construction. Not a stand-alone remedy.
		PLASTIC COVER	Thin plastic cover over exposed soils.	Applicable during construction. Not a stand-alone remedy.

Figure 3-3
Initial Screening of Technologies and Process Options for Soil (page 2 of 4)

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
REMOVAL	EXCAVATION	CONVENTIONAL EQUIPMENT	Soils dug from the ground using conventional construction equipment.	Applicable; not a remedial action by itself.
DISPOSAL	OFFSITE	LANDFILL	Dispose of soils in offsite landfill.	Lack of suitable disposal facilities; onsite remediation preferred by regulatory agencies. Army regulations prohibit offsite landfilling of explosives.
	ONSITE	BACKFILL LAGOONS	Dispose of treated soils in lagoon excavation.	Soils must meet RAOs.
IMMOBILIZATION	PHYSICAL/ CHEMICAL FIXATION	SOLIDIFICATION/ STABILIZATION	Various methods of immobilizing contaminants within soil matrix without altering waste characteristincs (e.g. with cement/silicate or encapsulation)	Potentially applicable.
	VITRIFICATION	IN SITU	Glassification of waste in place using high electric current.	Not tested for these contaminants and soil; not demonstrated full-scale.
		EX SITU	Glassification of excavated waste in onsite or offsite plant.	Not tested for these contaminants and soil; not demonstrated full-scale.

Eliminated from further consideration

Figure 3-3
Initial Screening of Technologies and Process Options for Soil (page 3 of 4)

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
TREATMENT	THERMAL	HIGH-TEMPERATURE THERMAL DESTRUCTION (E.G., INCINERATION)	Destruction of contaminants in high-temperature incinerator or other device.	Applicable. Demonstrated at other explosives-contaminated sites.
		LOW-TEMPERATURE THERMAL DECOMPOSITION	Decomposition at moderate pressures (<25 ATM) and temperatures (100-350°C)	Found ineffective in USATHAMA studies on explosives-contaminated soils at Louisiana Army Ammunition Plant (IT, 1987).
	BIOLOGICAL	COMPOSTING	Contaminated soils mixed with organic amendment and aerobically biodegraded.	Applicable. Demonstrated by USATHAMA treatability studies at UMDA to reduce explosives contamination in soil (Roy F. Weston, Inc., 1991a).
		IN SITU BIODEGRADATION	Nutrients and oxygen delivered to soils.	Not demonstrated for these contaminants and soils. Difficult to assure amendments supplied in proper proportions to all parts of soil matrix. May not be effective at low explosive concentrations.
		SLURRY PHASE TREATMENT	Excavated soils slurried with water and nutrients and aerobically biodegraded.	Treatability studies have not demonstrated effectiveness (Argonne National Laboratory, 1991).
	PHYSICAL	AQUEOUS SOIL WASHING	Water used to leach contaminants from soils either in situ or ex situ.	Treatability studies indicate explosives-removal efficiency is below 90% (ARCO, 1982; EPA, 1992).
		SOLVENT EXTRACTION	Contaminants extracted with solvent from excavated soil.	Applicable. Removal rates >99% demonstrated (EPA, 1989b). Explosives-contaminated solvent requires further treatment.
		IN SITU VACUUM EXTRACTION	Volatile contaminants extracted from soil with vacuum wells.	Not feasible due to low volatility of contaminants.
		SIEVING/SCREENING	Excavated soils passed through screen to remove large particles.	Concentrating contaminants increases risk of detonation. Not a treatment by itself.
	CHEMICAL TREATMENT	OXIDATION	Chemical oxidation of contaminants to produce nontoxic material.	Explosives not susceptible to abiotic oxidation.
		REDUCTION	Chemical reduction of contaminants to produce nontoxic material.	Not demonstrated for these contaminants and soils. May produce toxic byproducts.

Eliminated from further consideration

Figure 3-3
Initial Screening of Technologies and Process Options for Soil (page 4 of 4)

No Action. The No Action alternative does not reduce human exposure or contaminant toxicity, mobility, or volume. However, as required by the NCP, it will be carried through subsequent screening and analysis as a baseline reference point for review and comparison of various technologies.

Institutional Controls. Access restrictions are methods of minimizing or preventing human exposure to contaminants, but they do not reduce the toxicity, mobility, or volume of contaminants. Access restrictions were rejected because they would be inconsistent and ineffective with the future use scenarios proposed for the site. The UMDA is scheduled for realignment under the BRAC program, and the Army will eventually vacate the site. At that time, ownership and use of the land will be transferred to another agency or to private interests. Although specific future development plans for the site have not been prepared, both EPA and the State of Oregon have indicated a strong preference for maintaining the flexibility to use the land for residential or light industrial purposes. Deed and zoning restrictions, fences, warning signs, and similar controls to limit use of the site would be contrary to this preference and, therefore, this technology is not considered further in this FS.

Monitoring is not a suitable remedial technology in and of itself because it does not actively prevent exposure to contaminants nor does it reduce contaminant toxicity, mobility, or volume. However, monitoring is commonly selected for further consideration in combination with other remedies as a means to evaluate the short-term impacts

and long-term effectiveness of those remedies. Therefore, monitoring is carried forward for further consideration.

Containment. Waste containment technologies are generally intended to minimize direct contact with contaminated soil and/or to reduce the mobility of contaminants by imposing a barrier. The toxicity of the contaminants is not reduced. Containment could potentially be accomplished (to varying degrees) by covering the site with clean soil or an engineered cap, or revegetating the site. All three of these methods are retained for further consideration.

Surface controls are measures that are intended to provide short-term rather than long-term control of contaminants. As such, they are not suitable remedial measures in and of themselves. However, they can be used to provide temporary contaminant control during the implementation of other remedies, and are thus retained for further evaluation.

Removal. Removal of contaminated soil from the lagoons would minimize the exposure to individuals using the site in the future. However, removal alone would not reduce the toxicity, mobility, or volume of the contaminants in the soil and is therefore not an appropriate stand-alone technology. It is carried through as an option to be used in conjunction with potential ex situ treatment and disposal alternatives.

Disposal. If the contaminated soil is removed from its present location at the lagoons, it will require disposal, either with or without treatment. Onsite disposal, either replacement in the lagoon excavation or placement elsewhere onsite, would be applicable if the soil is first treated to meet the RAOs. Onsite disposal without treatment would require long-term containment and management of the soil and was considered inappropriate for further consideration.

Offsite disposal in a hazardous or solid waste landfill was considered inappropriate for several reasons: (1) EPA, ODEQ, and the Army have expressed a preference for onsite remediation, reflecting EPA's and ODEQ's policy to pursue response actions that involve treatment versus land disposal; (2) offsite disposal increases the short-term risks of an accident and subsequent public exposure associated with the transportation of the contaminated soil; (3) there is no evidence that an offsite landfill would be willing to accept explosives-contaminated soil, with or without treatment; and (4) Army regulations require the decontamination of debris or equipment before it is released to the public sector for unrestricted use.

Immobilization. Immobilization can reduce the mobility (and, potentially, the leachable toxicity) of contaminants. Physical immobilization involves blending the contaminated soil with stabilizing materials, whereas chemical immobilization uses a chemical reaction to bind the contaminants into a material that reduces mobility. A variety of immobilization techniques have been used at other sites, though not specifically for

explosives contaminants. However, because of the widespread use of physical and chemical immobilization, they are carried forward for further evaluation.

Vitrification is an immobilization process whereby a high voltage current is passed through the contaminated soil (either in situ or ex situ), resulting in the formation of a glass-like substance that resists contaminant leaching. Vitrification has been demonstrated in bench-scale tests (although not specifically for explosives-contaminated soils), but successful large-scale tests have not been conducted. Therefore, it is not retained for further consideration.

Thermal Treatment. Thermal treatment is the thermodynamic oxidation at elevated temperatures of combustible organic compounds. High-temperature combustion usually involves the application of direct heat, while low-temperature decomposition involves indirect heat.

High-temperature combustion (e.g., incineration) is widely demonstrated as an effective means of remediating organic-contaminated soils. A pilot scale rotary kiln incinerator was used to demonstrate a destruction efficiency of greater than 99.99 percent for explosives contaminants at the Savanna Army Depot Activity, Savanna, Illinois (EPA, 1989b). Other potentially applicable process options in this category are fluidized bed incineration and infrared conveyor furnace, both of which use temperatures similar to rotary kiln incinerators. All of these are carried forward for further evaluation.

Low-temperature thermal decomposition was evaluated for explosives-contaminated soil, but treatability studies indicate that it does not adequately remove the explosives contaminants from the soil (IT, 1987). Therefore, it is not considered further.

Biological Treatment. Biological treatment relies on the activity of microorganisms to degrade organic contaminants. It can be conducted both in situ and ex situ.

Composting is an innovative method of ex situ biodegradation for explosives-contaminated soils. The NCP encourages the evaluation of innovative technologies that might provide effectiveness or cost enhancements over previously demonstrated technologies, for which sufficient site-specific treatability studies are available [40 CFR 300.430(e)(5)]. Although composting has not been demonstrated for full-scale remediation, site-specific treatability studies have shown that it can effectively reduce contaminant concentrations and soil toxicity by greater than 90 percent (Roy F. Weston, 1991; ORNL, 1991). Therefore, composting was selected for further evaluation.

In situ biodegradation has been considered only conceptually for UMDA. It has been relatively unsuccessful in vadose zone applications at other sites because of the difficulty in maintaining a relatively uniform and constant distribution of nutrients, moisture, and, for aerobic processes, oxygen. At UMDA, nutrient distribution would be the primary limiting factor. As noted during the conduct of the ex situ composting studies, effective biodegradation of explosives contaminants appears to require the addition of organic amendment in the ratio of four parts amendment to one part soil (Roy F.

Weston, Inc., 1991). Mixing large volumes of amendment into the soil would require extensive soil handling and site disturbance, thus negating two of the primary benefits of in situ treatment.

Slurry-phase biological treatment involves diluting the contaminated soil with water and feeding the resulting slurry to a system containing bacteria. Slurry phase treatment was considered conceptually viable in an evaluation by Montemagno and Irvine (1990), but in treatability studies to date, less than a 90 percent destruction and removal efficiency has been achieved (Argonne National Laboratory, 1991). Because the effectiveness has not yet been demonstrated, this technology is not considered further in this FS.

Physical Treatment. Physical treatment technologies typically involve the transfer of contaminants from one medium to another, with or without concentration, for the purpose of facilitating final treatment or disposal.

Solvent extraction involves mixing an appropriate solvent with the contaminated soil, either in situ or ex situ, to remove contaminants. Studies conducted by USATHAMA using an acetone-water mixture indicate that solvent extraction of explosives-contaminated soils results in removal of greater than 99.5 percent of the explosives (EPA, 1989b). Although transfer of the explosives from the soil to the solvent would not constitute a remedial technology in and of itself, it is considered further for possible use in combination with other technologies.

Aqueous extraction uses water as the extracting medium. Bench-scale studies conducted by USATHAMA indicate that removal efficiencies are generally poor, ranging from 49 to 99 percent in one study (ARCO, 1982) and 23 to 73 percent in another study (EPA, 1992). This is consistent with the low aqueous solubility of the explosives as shown in Table 2-4, and low-solubility limits the viability of both in situ and ex situ aqueous soil washing. This technology was not considered for further evaluation.

In situ vacuum extraction, or air stripping, uses heated air to volatilize and remove organic compounds from the soil. It is not considered further because the low vapor pressure and volatility of the explosives makes this an ineffective phase separation technology.

Screening and sieving are physical process options that are typically used when the contamination is preferentially associated with a particular size fraction of a medium that has a range of size fractions. Screening allows the less contaminated fractions of the medium to be separated out, leaving a smaller volume of medium with higher concentrations of contamination. While this could improve the efficiency of remediation with some contaminants, concentrating explosives increases the risk of detonation. Therefore, USATHAMA has indicated a preference for limiting screening to the removal of large rocks and debris that would interfere with other treatment options (USATHAMA, 1991a).

Chemical Treatment. Chemical treatment methods involve the use of oxidizing and/or reducing agents to selectively convert organic compounds to less hazardous forms. In studies conducted by USATHAMA (IT, 1987), neither oxidation nor reduction were successful. The explosives typical of the Explosives Washout Lagoons were found to be extremely resistive to oxidative degradation, and chemical reduction resulted in compounds that were hazardous.

3.4.3 Final Screening of Technologies

Figure 3-4 shows the general response actions, technologies, and process options remaining after the initial screening. These technologies and process options are considered in greater detail below according to the criteria of effectiveness, implementability, and cost. Summary comments for each criterion are shown in the table and a more detailed discussion follows.

3.4.3.1 No Action

The No Action general response action involves no technology, requires no implementation, is not effective in reducing toxicity, mobility, or volume of the waste, and incurs no direct cost. Some natural degradation of explosives might occur, but based on their continued presence 25 years after discharges to the lagoons were discontinued, the rate of recovery is expected to be slow. This alternative is included as a requirement of the NCP and provides a baseline for comparison with the other technologies.

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTIONS	EFFECTIVENESS	IMPLEMENTABILITY	COST
NO ACTION	NONE	NONE	Does not mitigate contamination.	Easily implemented. Additional evaluation required per NCP. Does not meet ARARs.	Low
INSTITUTIONAL CONTROL	MONITORING	GROUNDWATER	Useful for evaluating effectiveness of remediation. Does not mitigate contamination.	Wells in place.	Low
		SOIL	Useful for evaluating effectiveness of remediation. Does not mitigate contamination.	Easily implemented.	Low
		AIR	Useful for monitoring short-term impacts during remediation. Does not mitigate contamination.	Easily implemented.	Low
CONTAINMENT	COVER	ENGINEERED CAP	Effective at preventing exposure, reducing contaminant mobility. Susceptible to long-term degradation.	Technically feasible. Will restrict future land use. Unacceptable to agencies as a stand-alone remedy.	Moderate
		CLEAN SOIL	Effective at minimizing exposure. Does not substantially reduce contaminant mobility. Susceptible to long-term degradation. Provides site restoration.	Conventional construction. Will not meet ARARs as stand-alone remedy.	Low
		VEGETATION	Minimally effective at reducing exposure and contaminant mobility. Provides site restoration.	Easily implemented.	Low
	DUST CONTROL	WATER SPRAYING	Effective at minimizing short-term impacts during remediation. Requires reapplication.	Conventional construction.	Low
		PLASTIC COVER	Effective at mitigating short-term impacts during remediation.	Conventional construction.	Low

Eliminated from further consideration

Figure 3-4
Evaluation of Process Options for Soil
(page 1 of 2)

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTIONS	EFFECTIVENESS	IMPLEMENTABILITY	COST
REMOVAL	EXCAVATION	CONVENTIONAL EQUIPMENT	Required to use ex situ treatment technologies.	Conventional construction.	Low
IMMOBILIZATION	PHYSICAL/ CHEMICAL FIXATION	SOLIDIFICATION/ STABILIZATION	No data available for these contaminants and soils. Would require treatability studies.	Requires full site-specific treatability studies.	Low to high depending on process option.
TREATMENT	THERMAL	INCINERATION	Proven effective and reliable.	Full-scale implementation demonstrated. Incinerators available from several vendors.	High
	BIOLOGICAL	COMPOSTING	Not yet proven. Full-scale treatability studies show effective reduction of contamination.	Low-level technology; expected to be easily implemented. Onsite treatability studies show feasibility.	Moderate
	PHYSICAL	EX SITU SOLVENT EXTRACTION	Effects removal, but does not reduce toxicity or mobility. Follow-on treatability studies required.	Moderately complex technology; implementation not demonstrated. Requires additional treatment and disposal of residuals.	Moderate

Eliminated from further consideration

Figure 3-4
Evaluation of Process Options for Soil
(page 2 of 2)

For the UMDA Explosives Washout Lagoons, No Action is an alternative unacceptable to the regulatory agencies because of the potential for future exposure.

3.4.3.2 Institutional Controls

Monitoring (soil, groundwater, and air) was the only institutional control carried forward to this stage of screening.

Effectiveness. While not an effective means of mitigating contamination, monitoring could be beneficially used to measure the short-term impacts and long-term effectiveness of remedial activities.

Soil monitoring would be an effective supplement to remedial activities that involve either the removal of contaminated soil or in situ immobilization/treatment. If an alternative involving removal is implemented, soil sampling could be used to verify that a sufficient soil volume has been excavated. Alternatively, if in situ immobilization or treatment is selected, soil sampling could be used to verify that mobility and/or toxicity have been reduced. In either case, the sampling program could be statistically designed to provide a known level of confidence regarding the effectiveness of remediation.

Groundwater monitoring is currently conducted on an installation-wide basis as part of the UMDA RI/FS. The data could be used to monitor impacts on the groundwater from soil remedial activities. Data collected from the monitoring wells would be required in the event that residual contamination remains in the soils following remediation.

Air monitoring would be of greatest benefit during the progress of soil-disturbing activities. The explosives contaminants have a low volatility, so airborne contamination is not normally of concern. However, in the event that soils are excavated or treated in situ, the potential exists for the production and airborne dispersion of contaminated particulates. During such activities, an air monitoring program that includes the regular use of a particulate counter would provide a means of determining when additional dust controls were required.

Implementability. Sampling programs for the lagoons would use standard sampling technology and would be relatively easy to implement.

Cost. Additional sampling of existing groundwater monitoring wells can be performed at a relatively low cost. Likewise, air monitoring and soil sampling would represent a relatively low fraction of the overall cost of remediation.

3.4.3.3 Containment—Engineered Cap

Covering the lagoons using an engineered cap is a technically feasible remedial option under the containment general response action. Several process options, consisting of variations in the material of construction, are available under the general technology of an engineered cap. Examples of caps include clay, synthetic membranes, asphalt, asphaltic concrete, portland cement, concrete caps, and multimedia combinations of these caps.

Effectiveness. Capping is effective at limiting infiltration, thereby decreasing additional leaching of contaminants from the unsaturated soil into the groundwater below. Capping also provides a barrier that minimizes the potential for dermal contact and ingestion, and isolates the contaminants, decreasing their potential to become airborne and enter the body by inhalation. While decreasing mobility, capping does not decrease toxicity or volume.

Implementability. From a technical standpoint, capping could be easily implemented at the Explosives Washout Lagoons. However, this technology alone would not satisfy State of Oregon remedial requirements, unless ODEQ agreed that removal and/or treatment of contaminated soil was not feasible. Both ODEQ and EPA have indicated that, in this case, removal followed by treatment is preferred.

Cost. An engineered cap is moderately expensive. Application of a simple cover consisting of a clean soil would be inexpensive.

Summary. An engineered cap is eliminated from further evaluation. As a singular remedial action, it fails to meet regulatory agency preferences. As a secondary measure to be used following removal and/or treatment of most of the contaminants, the relative expense is unlikely to be justified by the benefit when compared to other containment options.

3.4.3.4 Containment—Soil Cover

Covering the lagoons with a layer of clean soil is a second feasible containment option. Soil could be obtained either from undisturbed areas of the UMDA installation or from an offsite location.

Effectiveness. A soil cover is less effective than an engineered cap at limiting infiltration. However, since potential evapotranspiration rates in the region (32 inches per year) exceed precipitation rates (8 to 9 inches per year), a cover of clean soil would possibly reduce the amount of precipitation reaching underlying contaminated soil. A clean soil cover would also reduce the potential for direct contact with contaminated soil, both by humans and by the root systems of plants. However, a soil cover alone, without other remedial measures, would not reduce the toxicity or volume of contaminants and would provide limited reduction in mobility.

A soil cover would possibly be more susceptible to wind and stormwater erosion than an engineered cap. However, such deterioration could be mitigated through appropriate grading and placement of vegetation.

Implementability. Placing a soil cover over the lagoons would be relatively simple. There are several areas of undisturbed, uncontaminated soil on the UMOA installation from which materials could be obtained. As with an engineered cap, use of a soil cover alone without other remediation would not be acceptable to the regulatory agencies because it fails to remove or treat any of the contamination.

Cost. A soil cover would involve a relatively low cost.

Summary. A soil cover is retained for further evaluation, but only in combination with other remedial options. In particular, it could be considered in the event that most but not all of the contaminants are removed from the lagoons, leaving low-level residual contamination.

3.4.3.5 Containment-Vegetative Cap

A third containment option for remediating the lagoons involves replanting vegetation in the area.

Effectiveness. Without other remedial measures to reduce contaminant concentrations, a vegetative cap would be an ineffective means of containment. As discussed in Section 2.7, explosives concentrations greater than 1,000 ppm have been determined to be toxic to plant life. Concentrations exceeding that level are frequently observed in surface soil samples from the lagoons, and thus it is unlikely that a vegetative cover could be sustained. This premise is supported by the fact that, in their current condition, the bottoms, sidewalls, and berms of the lagoons support virtually no plant life.

A vegetative cap could be a moderately effective means of stabilizing either treated soil or a clean soil cover by minimizing wind and stormwater erosion. However, its utility is somewhat limited because of the semi-arid conditions found at UMDA. As noted in Section 2.2, native vegetation is relatively sparse and consists largely of desert grasses that are unlikely to provide complete soil stabilization. A more substantial vegetative cover would require long-term maintenance in the form of extensive irrigation. The desire to minimize long-term maintenance and the need for water conservation in the region makes irrigated vegetation an unfavorable option.

Implementability. Because of the low rate of precipitation, some level of irrigation might be required until vegetation is established. Proper selection of native species would reduce the length of time irrigation is required.

Cost. Costs for revegetation would be relatively low.

Summary. A vegetative cover is eliminated from further consideration as a singular remedial technology because of the phytotoxicity of existing surface soil contaminant concentrations. However, revegetation using native species is retained for consideration in combination with other technologies that might result in a soil surface with lower contaminant concentrations.

3.4.3.6 Containment—Surface Controls

Dust control using a water spray or plastic covers is a short-term containment alternative. It would most likely be used during any remedial construction activities that could result in disturbing the soil and creating an airborne contaminant hazard.

Effectiveness. Dust control would be a necessary and useful interim technology to minimize contaminant dispersion; it would not be considered a viable long-term remedial technology because it does not reduce the toxicity or volume of the waste and requires intensive long-term maintenance. While airborne dispersion of contaminants would be reduced, excessive water spraying could increase leaching of contaminants to the groundwater.

Implementability. While easily implemented and inexpensive as a short term measure, spraying or using a plastic cover would require excessive maintenance if used for a long period.

Cost. Costs for short-term dust control would be relatively low.

Summary. Dust control will be retained as a useful measure during remediation, to be combined with other actions.

3.4.3.7 Removal Using Conventional Equipment

Effectiveness. Removal would reduce the volume of contaminated soil present at the lagoons, but would not be an effective stand-alone remedial measure. However, all of the ex situ process options would require removal of contaminated soil, and excavation using conventional equipment and methods would be an effective and appropriate means of doing so.

Implementability. The appropriate excavation technology depends on the depth, volume, location, and characteristics of the material to be excavated. The contaminated soil of the Explosives Washout Lagoons consists primarily of dry sands and gravels located in an open, semi-arid setting with no overhead or underground obstructions. The topography is such that excavations of up to 25 feet below ground surface could be constructed with sideslopes sufficient to minimize any need for shoring. For deeper excavations, shoring would probably be required because sloped sides would encounter the escarpment to the southeast of the lagoons. In either case, conventional construction equipment could be used (e.g., scrapers, large backhoes, front-end loaders, and drag lines).

At the explosives concentrations detected during the site investigations, detonation of the soil is not expected. However, appropriate safety measures would be implemented to further reduce the potential for detonation.

Cost. Excavation with these conventional types of construction equipment is relatively inexpensive on a per-yard basis.

Summary. Excavation is retained for further consideration in combination with other remedial technologies.

3.4.3.8 Immobilization (Physical/Chemical Solidification/Stabilization)

Technologies and process options falling under the immobilization general response action are those that limit the solubility or mobility of contaminants within the soil matrix, with or without changing the physical characteristics of the matrix. They include stabilization, solidification/stabilization, and sorbent solidification. Solidification alone generally implies that the matrix is transformed into a solid monolith for the primary purpose of structural integrity. Stabilization generally implies that contaminants within the matrix become physically or chemically bound.

Effectiveness. Solidification/stabilization would be accomplished by mixing the soil with various materials such as portland cement, certain pozzolans, silicates, thermoplastics, and bitumens to form a solid matrix that incorporates the explosives contaminants.

Immobilization could be performed either in situ (with the solidified mass left in place) or ex situ (with the solidified mass land-disposed onsite or offsite). The contaminants might or might not be chemically bound to constituents within the matrix. Site-specific treatability studies have not been performed, so the chemistry and the effective reduction in contaminant mobility cannot be evaluated. Solidification/stabilization would not reduce the toxicity or volume of the waste.

EPA considers solidification alone without stabilization inadequate as a permanent treatment method. For semivolatile organic compounds such as the explosives of concern at UMDA, the following is excerpted from an EPA fact sheet entitled "Immobilization as Treatment" (EPA, 1991a). "The Superfund policy is as follows:

> "Selection of immobilization for semivolatile and nonvolatile organics generally requires the performance of a site-specific treatability study or onsite-specific treatability study data generated on waste that is very similar (in terms of type of contaminant, concentration, and waste matrix) to that to be treated and that demonstrates, through Total Waste Analysis (TWA), a significant (i.e., a 90-99 percent reduction) in the concentration of chemical constituent of concern."

Implementability. While technical implementability seems favorable for solidification/ stabilization, administratively, the technology would require treatability studies to

demonstrate effectiveness. Effectiveness would be particularly difficult to demonstrate because testing to predict permanence is difficult.

Cost. The cost of solidification/stabilization varies greatly with the type of process used. Portland cement stabilization is relatively inexpensive, whereas some of the encapsulation techniques are very expensive and are currently being considered only for very limited applications. The necessary treatability studies to qualify solidification/stabilization for this site would add significantly to the cost.

Summary. Because treatability studies have not been done for the contaminants and soils of this site, solidification/stabilization is rejected.

3.4.3.9 Thermal Treatment

A variety of thermal technologies exists for the treatment of solids containing organic contaminants. These techniques thermally oxidize or pyrolyze combustible pollutants at elevated temperatures to produce the combustion products carbon dioxide and water. Other elemental constituents such as nitrogen, halogens, phosphorus, and sulfur are typically converted to acidic vapors. Thermal treatment is generally not appropriate for wastes containing significant concentrations of metals.

Advantages of thermal treatment of wastes are:

- Toxic components are permanently converted to harmless or less harmful compounds

- Thermal destruction is an ultimate treatment in itself, requiring no further treatment of residuals

Numerous types of thermal processes are available for the destruction of hazardous wastes both on- and offsite. Four types, selected on the basis of commercial availability and technical feasibility for application to explosives-contaminated soils, are described below. Three of these are onsite incineration methods: rotary kiln, infrared, and fluidized bed combustion. The only offsite treatment process option described is rotary kiln incineration, because of uncertain availability of offsite facilities that use alternate thermal treatment technologies. Other potential technologies, such as plasma arc reaction, were discarded because of the lack of commercial availability of either onsite or offsite facilities. The four potentially feasible types of thermal destruction can be described as follows:

- Rotary Kiln Incinerator (onsite). Waste is combusted in a refractory-lined kiln that is heated by burning fossil fuels. Exhaust gases pass through a secondary combustion chamber (afterburner) and air pollution control (APC) equipment. Minimal feed preparation is required. The primary residual produced is combusted soil from the incinerator and APC; air emissions are also produced. Scrubber water from the APC is

generally recycled. Rotary kiln incinerators are the most versatile and the most proven of all devices for waste soil incineration.

Onsite rotary kiln incinerators are available as either mobile or transportable units. Mobile units are small-capacity systems permanently installed on two or three trucks that are typically used at sites where the waste quantity ranges up to 20,000 tons. Projects where the waste quantity would exceed 20,000 tons can be conducted more effectively using transportable systems that occupy 5 to 30 trucks and that require onsite assembly. More pretreatment of the soil is required for a mobile unit to screen out rocks that might be acceptable in a larger transportable unit.

- Infrared Conveyor Furnace (onsite). Waste is combusted in a thermal desorber (or primary combustion chamber) that uses electrical resistance heating elements or indirect fuel-fired radiant U-tubes to generate thermal radiation. The waste can be heated in the absence of oxygen if necessary. Exhaust gases pass through a secondary combustion chamber and air pollution control equipment. Infrared treatment is expected to generate somewhat lower particulate emissions than rotary kiln incineration.

- Fluidized Bed Incinerator (onsite). Waste is combusted in a vertical reactor containing a heated, fluidized bed of inert granular material. The thorough mixing, high solids residence time, and high heat transfer provided by fluidized beds allow these systems to operate at lower temperatures and excess air levels than other incineration processes. Flue gas is separated from heavier particles in a solids separation cyclone.

- Fixed Rotary Kiln Incinerator (offsite). Offsite facilities use the same basic components as the mobile/transportable rotary kilns described earlier. Offsite incinerators are frequently used when the total waste quantity to be burned is below 2000 tons (McGowan and Ross, 1991).

Effectiveness. Based on the general effectiveness of thermal destruction methods for organics, treatment by any of the methods described above would be expected to meet the NCP objective of destroying contaminants to the maximum extent feasible. Full-scale field demonstration of rotary kiln incineration has a DRE of >99.99 percent for soils containing similar explosive compounds (Roy F. Weston, Inc., 1985, and USATHAMA, 1985). For this reason, treatment by rotary kiln incineration either on- or offsite is judged to be effective.

Neither infrared incineration nor fluidized bed incineration have been demonstrated on explosive contaminated soils. However, both have been highly effective with other organic contaminants. Infrared incineration has achieved a greater than

99.9999 percent DRE of polychlorinated biphenyls (PCBs) in contaminated soils in pilot scale tests (EPA, 1989a), and has been applied on both a pilot and commercial scale at several Superfund sites for petroleum, phenolic and nonhalogenated hydrocarbon solid wastes. Circulating bed combustors have been used successfully for contaminated soils having widely varying Btu values and composition, and have achieved consistently high DRE criteria (CDHS, 1991). Either of these technologies could be effective but would require additional study.

Implementability. The implementability of onsite rotary kiln incineration has been demonstrated at other Army installations, including the Louisiana and Cornhusker Army Ammunition Plants. Explosives concentrations at UMDA do not appear to be a constraint, since studies conducted by USATHAMA indicate that sediments with explosive concentration levels higher than those at the UMDA lagoons can be fed directly to the primary combustion chamber of an incinerator without exceeding acceptable safety limitations (Roy F. Weston, Inc., 1987).

Whether it would be more feasible to use a mobile or transportable rotary kiln unit depends upon the mass of soil to remediate. The actual mass will be determined after agency and public review of this FS. Masses representing varying degrees of residual risk were shown in Section 3.2. At the lower end of the range contemplated (approximately 3,700 to 6,800 tons) a mobile incinerator is favored; for example, VESTA Technology, Ltd., has suitable units with feed rates ranging from 1/2 ton per hour to 4 tons per hour (VESTA Technology, Ltd., 1992a). Other masses considered are

30,000 and 47,000 tons, and a transportable system having a nominal feed rate of 10 to 20 tons per hour would be more feasible. The number of commercial mobile units is somewhat more limited than their transportable counterparts. Sufficient land area is available around the lagoons for erection of either type of unit.

Commercial infrared systems are available but on a more limited scale than rotary kilns, thus a competitive bidding climate might not exist. Transportable infrared furnace units are available from Shirco and Continental Resource Recovery (CRR). The Shirco design, known for PCB and petroleum contaminated soils, is the most widely used infrared unit commercially available, and numerous pilot and commercial systems have operated successfully or are presently operating. Implementation would probably be possible.

Implementability of fluidized bed combustion technology is relatively uncertain. The Ogden circulating bed combustor was the only commercially available unit located during the screening. This single 5 tons per hour transportable circulating bed combustor, available from Ogden Environmental Services, has been used to treat soils containing petroleum and PCBs.

There are few offsite incineration facilities that are permitted to accept explosives-contaminated soils. The nearest potential candidate is the rotary kiln incinerator owned and operated by Aptus in Grantsville, Utah. This facility is capable of burning 300 tons per day and expects to have permits for processing explosives by early 1992

(Aptus, 1991). The incinerator owned and operated by Chemical Waste Management (CWM) in Sauget, Illinois, and the Aptus incinerator in Coffeyville, Kansas, can accept material that is reactive as long as it is not explosive (Aptus, 1991; Chemical Waste Management, 1991). Several of the major facilities, including Chemical Processors, Inc., Northwest EnviroService, Inc., and CWM (Port Arthur, Texas, facility), stated that they could not accept explosives contaminated soils (Chemical Processors, 1991; Chemical Waste Management, 1991; Northwest EnviroService, 1991).

Cost. The unit cost of mobile and transportable rotary kiln incineration is highly dependent on the total mass of soil; because of the fixed costs of site preparation, mobilization, and trial burns, the cost per ton increases as the total mass decreases. In a survey conducted by McCoy and Associates, Inc., unit operating costs estimated by two vendors of mobile rotary kiln incinerators ranged from $250 to $750 per ton (EPA, 1991d). In the same survey, vendor operating costs for transportable rotary kiln incinerators ranged from $200 to $450 per ton (EPA, 1991d). These costs did not include excavation, site preparation, or solids handling. McGowan and Ross (1991) estimated total incineration costs for Superfund sites, including excavation, permitting, and ancillary equipment, in the $200 to $650 per ton range. Explosives-contaminated soils were incinerated at the Cornhusker Army Ammunition Plant for $260 per ton (40,000 tons total) and the Louisiana Army Ammunition Plant for $330 per ton (102,000 tons total).

A recent cost estimate for infrared incineration is $400 per ton (CRR, 1991), excluding permitting, excavation, or ancillary equipment costs. The estimated incineration cost for the Ogden circulating bed combustor is $150 to $200 per ton, excluding permitting, excavation, and ancillary equipment. No information was provided as to premiums for low soil masses. These costs are comparable to the low- to mid-range costs for a rotary kiln incinerator.

Estimated offsite incineration costs obtained from Aptus and CWM for handling the soil from the UMDA lagoons were $1,500 to $1,600 per ton. Additional transportation costs could be as high as $430 per ton (Aptus, 1991, and CWM, 1991). While this option is effective, and may be implementable, it is not cost-effective.

Summary. Onsite rotary kiln incineration is selected for further detailed evaluation because it is the single technology whose effectiveness and implementability have been demonstrated in similar applications. Offsite rotary kiln incineration is rejected because of the high cost. Infrared and fluidized bed incineration, although expected to be effective, were not selected for detailed evaluation because of the lack of demonstrated effectiveness for explosives-contaminated soil and potential constraints on availability.

3.4.3.10 Treatment by Composting

Composting is a biological treatment process by which organic materials or contaminants are decomposed by microorganisms. The process can reduce concentrations of toxic organics and result in the production of less toxic organic and inorganic by-products and energy in the form of heat. This heat is trapped within the compost matrix, leading to the self-heating that is characteristic of composting.

Composting is a well-developed technology for municipal wastewater sludges, yard and agricultural wastes, and other similar solid wastes, but its application to explosives-contaminated soil is innovative. USATHAMA has been performing bench-scale and pilot-scale studies of this application since the early 1980's. Studies conducted using contaminated soil from the UMDA lagoons indicated that the extractable concentrations of the explosives in the soil were significantly reduced (90 to 99 percent) by the aerobic microorganisms (Roy F. Weston, Inc., 1991a). The most effective amendments have been found to be agricultural and animal waste (Roy F. Weston, Inc., 1991a). These amendments provide a source of natural microorganisms and the high carbon content needed to sustain microbial growth. The efficiency of the composting process is affected by temperature, moisture content, oxygen content, pH, and concentrations of the organic substrates and inorganic nutrients (e.g., nitrogen and phosphorus). Control of the self-generated heat is especially critical, since the desired microbial activity can be seriously inhibited by temperature extremes.

Three types of composting systems have been considered by USATHAMA. They differ in their technical complexity and the degree to which they control temperature, moisture content, and aeration. They are:

- Static Pile. The soil and amendment mixture is composted in a pile without mixing of any type. The pile might be aerated using blowers to introduce air into the bottom of the pile; this helps to maintain oxygen levels and disperse heat. However, the pile is likely to develop temperature and moisture gradients and pockets of anaerobic activity.

- Windrows. The soil and amendment mixture is formed into elongated piles (windrows) and turned periodically using a mechanical composter. Turning helps aerate the mixture and distribute heat and moisture. However, heat is lost during turning, which can temporarily slow the composting process.

- Mechanically Agitated In-Vessel (MAIV). The soil and amendment mixture is placed in a reactor vessel and agitated periodically. Air and water are introduced to control temperature and moisture content. A relatively even distribution of heat, moisture, and microbial activity can be achieved, but at a higher cost than for static pile or windrow systems.

Effectiveness. Previous studies of composting at other sites have demonstrated the susceptibility of explosives and propellants to microbial degradation (Williams et al., 1988 and Woodward-Clyde Consultants et al., 1990). As a follow-on to those studies, a site-specific composting optimization study was conducted at UMDA to evaluate the relative effectiveness of three different organic amendment compositions and soil loadings ranging from 7 percent to 40 volume percent of the total mixture (Roy F. Weston, Inc., 1991a). The evaluations were conducted using both static pile and MAIV composting technologies. In addition, a bioaugmented investigation using a microbial inoculum was conducted in a static pile. Table 3-6 summarizes the results of the tests conducted.

As seen in the table, both TNT and RDX demonstrated significant degradation (97 to 99 percent) when composting parameters were optimized. Final TNT and RDX concentrations of 4 to 18 mg/kg were achieved using an agitated system, horse or cow manure-based amendment, and a soil loading of 10 to 25 volume percent. Mixing (using the MAIV) clearly enhanced the rate and extent of degradation. The effectiveness of degradation was also significantly enhanced by using an amendment containing horse or cow manure and by limiting soil loading to no more than 30 volume percent of the total compost volume. Chicken manure-based amendments and soil loadings greater than 30 volume percent appeared to be markedly less effective. The compost pile inoculated with microbes (not shown in the table) exhibited little or no explosives degradation, even after 90 days.

Table 3-6
Summary of Results from UMDA Composting Optimization Study[a]

Compost System[b]	Amendment Composition[c]	Soil Loading[d]	Initial/Final Concentrations (mg/kg)[e]		Percent Decrease in Concentrations[f]	
			TNT	RDX	TNT	RDX
MAIV	A	10	3,452/90	1,011/104	97	90
MAIV	B	10	3,126/5.6	575/3.8	99.8	99.3
MAIV	C	25	5,208/14	597/18	99.7	97.0
MAIV	C	40	6,950/209	754/621	97	18
SP	A	7	1,144/107	776/213	91	73
SP	A	10	4,984/200	1,008/542	96	46
SP	A	20	5,716/331	1,076/902	94	16
SP	A	30	7,908/174	1,178/924	98	22
SP	A	40	9,858/2,086	1,572/1,674	79	0
SP[g]	A	10	3.84/5.82	1.96/1.96	NA	NA
SP	C	10	3,850/41	618/46	98.9	93

[a]Summarized from Roy F. Weston, Inc. (1991a).
[b]MAIV = Mechanically Agitated In-Vessel (Fairfield reactor).
SP = Aerated static pile.
[c]Composition A: Potato waste (35%), sawdust (30%), chicken manure (20%), apple pomace (15%).
Composition B: Horse manure/straw (50%), alfalfa (32%), buffalo manure (10%), horse feed (8%).
Composition C: Cow manure (33%), alfalfa (22%), sawdust (22%), potato waste (17%) apple pomace (6%).
[d]Volume percent of total compost mixture.
[e]Concentrations in leachate from acetonitrile extraction of compost mixture at day zero and day 44 (MAIV) or day 90 (SP).
[f]Based on initial concentrations after the addition of amendment.
[g]Control test, uncontaminated soil.

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Treatability testing using windrow technology has not yet been completed. Because aeration and heat distribution would be provided through periodic turning, windrow composting is anticipated to have an effectiveness similar to the MAIV (Roy F. Weston, Inc., 1991b). This is to be confirmed during ongoing treatability studies (Roy F. Weston, Inc., 1992).

Implementability. Composting would be relatively easy to implement from both a technical and administrative standpoint. Use of the MAIV would require a moderate level of technology while a windrow or static pile system would require a low level of technology. The necessary amendments are readily available locally and could be trucked in with conventional hauling equipment. The soil and amendments could be combined using a front-end loader, and conventional equipment (either a windrow turner or an MAIV) could be used for mixing. Control of the critical parameters (temperature, moisture, air) would be the most difficult aspect of implementation and would require careful evaluation during the remedial design.

Administratively, composting would be attractive for two reasons:

- Treatability studies have demonstrated its effectiveness on the actual contaminated soils of the lagoons, thus increasing the level of confidence in this otherwise innovative technology. These site-specific studies would enhance acceptability to the regulatory agencies and the public.

- To date, no explosives-contaminated NPL sites have been remediated by composting. An opportunity exists to demonstrate that composting could be used as an effective alternative to incineration.

Cost. Full-scale excavation and composting using the MAIV system would be relatively expensive at $330 to $650/ton (costs developed in Section 4.2.4). However, the cost of composting using windrows is expected to be significantly lower at about $210 to $390 per ton of soil (costs developed in Section 4.2.4).

Summary. Composting is retained for detailed analysis on the basis of its feasibility as demonstrated by onsite treatability testing, attractiveness as an innovative technology, and its potentially lower cost as compared to incineration.

3.4.3.11 Treatment by Solvent Extraction

Ex situ solvent extraction systems remove contaminants from the excavated soil by transfer of the contaminant to a solvent phase. Typically, the contaminated solvent is then subjected to a fractionation process such as distillation to remove the contaminant. The fraction containing the contaminant must be treated, either to stabilize the contaminant or destroy it using a method such as incineration or oxidation. Alternately, the entire volume of solvent could be treated.

Effectiveness. Solvent extraction has been demonstrated on a laboratory scale to be an effective means of removing explosives contaminants from soil. A study conducted by USATHAMA (EPA, 1989b) used acetone as the solvent, since all of the explosives of interest were either somewhat or easily dispersible in acetone at room temperature. Initial concentrations of explosives in the soil ranged from 1,200 µg/g to 420,000 µg/g. Final concentrations were 6 to 17 µg/g, for an extraction efficiency of greater than 99.5 percent.

The limitations of solvent extraction arise upon consideration of the fate of the extract. In the study referenced above, the acetone was recovered by boiling the mixture, leaving a small amount of acetone with the explosives to maintain them in a wet state and reduce the potential for detonation. While this reduces the volume of contaminated media, it is not a final treatment. The study concluded by indicating that the acetone/explosives mixture could then be incinerated. However, the production of a concentrated explosives mixture, particularly entrained in a flammable solvent, is generally unacceptable to the Army because of the stringent requirements imposed on facilities that process detonatable concentrations. In addition, it is unlikely that a commercial incinerator would be willing to accept a potentially explosive mixture.

Implementability. The process would not be easily implemented from a technical or administrative perspective. Considerable equipment would be needed to perform the multiphased treatment processes needed for complete remediation. In addition, the design of a fractionation system would have to incorporate potentially costly explosion

safety controls, because fractionation of the contaminants would normally result in concentrating them to potentially reactive levels.

Administratively, the process is unproven for explosives. Treatability studies would be required to demonstrate the solvent and resulting concentrated explosive contaminants would be adequately managed.

Cost. Cost would be expected to be high because of the additional treatability testing required, the design and mobilization of expensive equipment, and the need to have process equipment for each of the several phases leading to complete remediation of the soil.

Summary. Ex situ solvent extraction is rejected on the basis that it is undemonstrated for this site and these contaminants, would require extensive treatability testing to demonstrate viability, and would potentially require costly design elements to mitigate safety concerns.

3.5 Selection of Specific Alternatives

In Sections 3.3 and 3.4, many response actions, technologies and associated process options were screened for use on this site using the general criteria of implementability,

effectiveness and cost. The options selected for further evaluation are shown in Table 3-7.

Table 3-7 Remedial Options Selected for Detailed Evaluation		
General Response Actions	**Technologies**	**Process Options**
No Action	None	None
Institutional Control	Monitoring	Groundwater Soil Air
Containment	Cover Dust Control	Soil Cover Vegetative Cover Water Spraying Plastic Cover
Removal	Excavation	Conventional Equipment
Treatment	Thermal Biological	Incineration Composting

These remedial actions will be combined to form the following three alternatives:

- Alternative 1: No Action

- Alternative 2: Incineration. This alternative includes excavation of the contaminated soil with conventional excavation equipment, testing of the soil below the excavation to verify removal of contaminants to an

acceptable level, onsite incineration, testing of incinerated soil to confirm effectiveness, and replacement of the incinerated soil in the excavation. The disturbed area would then be covered with clean soil and revegetated. Dust control and air monitoring will be used as necessary for worker safety during remediation.

- Alternative 3: Composting. This alternative includes excavation of the contaminated soil with conventional excavation equipment, testing of the soil below the excavation to verify removal of contaminants to an acceptable level, onsite composting, testing of the composted soil to confirm effectiveness, and replacement of the composted soil in the excavation. The disturbed area would then be covered with clean soil and revegetated. Dust control and air monitoring will be used as necessary for worker safety during remediation.

These alternatives will be analyzed in detail in Chapter 4.

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Description and Detailed Evaluation of Alternatives

Chapter 4

Description and Detailed Evaluation of Alternatives

This section presents a description and detailed evaluation of each of the three alternatives that were retained following the initial remedial actions screening. The alternatives are:

- Alternative 1: No Action
- Alternative 2: Incineration
- Alternative 3: Composting

These alternatives are then compared and key tradeoffs among them are noted. The purpose of this section is to present information relevant to selecting an appropriate remedy for soils contamination at the UMDA Explosives Washout Lagoons. The analyses were performed in accordance with the requirements of the NCP, CERCLA, SARA, and the Interim Guidance on Superfund Selection of Remedy (EPA, 1986). They are based on the institutional and technical criteria presented in Chapters 2 and 3.

4.1 CERCLA Evaluation Criteria

CERCLA, as amended by SARA, requires that the specific statutory requirements listed below be addressed in the ROD and supported by the FS report. Remedial actions must:

- Be protective of human health and the environment
- Attain ARARs (unless grounds are provided for invoking a waiver)
- Be cost-effective
- Use permanent solutions and alternative technologies or resource recovery technologies to the maximum extent practical
- Satisfy the preference for treatment that reduces toxicity, mobility, or volume as a principal element

CERCLA emphasizes long-term effectiveness and related considerations. In addition, as stated in Chapter 1, the NCP encourages the evaluation of innovative technologies.

To address these requirements, EPA has developed nine evaluation criteria (EPA, 1988b) to serve as the basis for conducting the detailed FS evaluation and, subsequently, selecting an appropriate remedial action. EPA categorizes these criteria as threshold, primary balancing, and modifying, as follows:

- Threshold Criteria

    - Overall protection of human health and the environment
    - Compliance with ARARs

- Primary Balancing Criteria

    - Long-term effectiveness and permanence
    - Reduction of toxicity, mobility, or volume
    - Short-term effectiveness
    - Implementability
    - Cost

- Modifying Criteria

    - State acceptance
    - Public acceptance

4.1.1 Threshold Criteria

Two of the criteria relate directly to statutory requirements that must ultimately be satisfied in the ROD. They are categorized as threshold criteria because any alternative selected to remediate the Explosives Washout Lagoons must meet them. They can be described as follows:

- Overall Protection of Human Health and the Environment—Describes how each alternative, as a whole, achieves and maintains protection of human health and the environment. This assessment draws on the assessments conducted under other evaluation criteria, especially long-term and short-term effectiveness and compliance with ARARs. It focuses on whether a specific alternative achieves adequate protection and describes how site risks are eliminated, reduced or controlled through treatment, engineering, or institutional controls.

- Compliance with ARARs—Describes how each alternative complies with ARARs, or if a waiver is required and how it is justified. The assessment also addresses other information from advisories, criteria, and guidance that the agencies agree is "to be considered." The detailed analysis summarizes which federal and State of Oregon requirements are applicable or relevant and appropriate for the specific alternative and how the alternative meets these requirements.

4.1.2 Primary Balancing Criteria

Five of the criteria are grouped together because they represent the primary factors upon which the analysis is based, taking into account technical, cost, institutional, and risk concerns.

- Long-Term Effectiveness and Permanence—Evaluates the effectiveness of each alternative in maintaining protection of human health and the environment after response objectives have been met. This assessment considers the magnitude of the residual risk (in this case, risk from soils that are not treated and risk from treatment residuals, if any), measured by numerical standards where possible. It also considers the adequacy and reliability of controls.

- Reduction of Toxicity, Mobility, and Volume Through Treatment—Evaluates the anticipated performance of the specific treatment technologies each alternative might employ. Where possible, numerical comparisons before and after remediation are presented. This assessment also considers the degree to which treatment is irreversible, the type and quantity of residuals that will remain following treatment, and the degree to which the treatment reduces the inherent hazards posed by the site.

- Short-Term Effectiveness—Examines the effectiveness of each alternative in protecting public health, worker health, and the environment during the construction and implementation of a remedy until response objectives have been met. The time until protection is achieved is also considered here.

- Implementability—Evaluates the technical and administrative feasibility of each alternative and the availability of required goods and services. Technical feasibility includes the ability to construct the system used, the ability to operate and maintain the equipment, and the ability to monitor and review the effectiveness of operations. Administrative feasibility refers to the ability to obtain normal legal approvals (e.g., site access), public relations and community response, and coordination with government regulatory agencies.

- Cost—Evaluates the capital and operation and maintenance (O&M) costs of each alternative. Capital cost refers to the expenditures required to develop and construct the facilities necessary to implement the alternative. O&M cost refers to the expenditures of time and materials throughout the course of the project, including costs to lease equipment.

The level of detail required to analyze each alternative against these evaluation criteria depends on the type and complexity of the site, the type of technologies and

alternatives being considered, and other project-specific considerations. This FS addresses a single site, a single environmental medium (soil), and a limited set of contaminants of concern (explosives). The detail presented in the following analyses has been focused appropriately.

4.1.3 Modifying Criteria

In accordance with RI/FS guidance (EPA, 1988), the final two criteria involving state and community acceptance will be evaluated following the receipt of state agency and public comments on the FS and the Proposed Plan. The criteria are as follows:

- State (Support Agency) Acceptance—Reflects the State of Oregon's apparent preferences among or concerns regarding the alternatives.

- Community Acceptance—Reflects the local communities' apparent preferences among or concerns about alternatives.

4.2 Analysis of Alternatives

4.2.1 Common Elements

Components that are common to two or three of the alternatives are discussed here as a group in order to limit redundancy in the subsequent discussion of individual alternatives.

4.2.1.1 Estimated Volumes of Contaminated Soil Requiring Remediation

Four potential excavation depths and associated volumes of contaminated soil were selected for evaluation in Section 3.2.2; the mass and volume of soil associated with each depth are shown in Table 3-5. For purposes of this FS, Alternative 2 (incineration) is considered a viable treatment option for all four cases. Alternative 3 (composting) is considered a viable option only for excavation depths of 2 feet, 5 feet, and 20 feet. Excavation to groundwater represents the cleanup-to-background scenario and was not considered an appropriate to evaluate such an excavation in conjunction with composting, case for Alternative 3 since composting as a treatment is not expected to reduce contaminant concentrations to background levels.

4.2.1.2 Excavation and Feed Preparation

Both Alternatives 2 and 3 would involve excavation of the contaminated soil and backfill of the excavated area. Costs for excavation and backfill were based on the following assumptions:

- Excavation, hauling, and backfill could be done using conventional equipment and technology (e.g. backhoes, front-end loaders, dump trucks, scrapers).

- For excavations to a depth of 20 feet below the lagoons, sides would be sloped as appropriate for sideslope stability and shoring would not be required. The slope would have the added benefit of removing the lagoon berms.

- For an excavation to groundwater (47 feet below the lagoons), a stepped or vertical-sided excavation is assumed because of topographic constraints, with appropriate shoring required. A tied-back retaining wall or similar construction could be used, and construction equipment could enter along a ramp constructed through the retaining wall.

- The soil would be hauled to a predetermined location near the treatment area, and following treatment would be returned to the excavation. The

distance between the lagoons and the treatment area is assumed to be 2000 feet. (Costs to prepare temporary stockpile pads at the treatment area are included in the site preparation costs for individual alternatives.)

- Excavation and backfill would be performed in accordance with CERCLA site health and safety requirements implemented under the Occupational Safety and Health Administration (OSHA) (29 CFR 1910.120). It is assumed that no respiratory protection would be required, but that the contractor would use appropriate dust control methods and would monitor for airborne particulates.

- The backfill material would consist primarily of treated soil; it would be compacted only to the degree required to prevent significant additional settling.

- The treated soil would be covered by a minimum of 2 feet of clean soil, obtained from an undisturbed area of the UMDA site. The clean soil would be collected using a conventional scraper or similar equipment. The distance from the area of clean soil to the lagoons is assumed to be 1 mile.

Based on experience with similar site conditions, excavation and hauling costs charged by a contractor for an unshored, uncontaminated excavation are typically $10 per cubic

yard of soil. These costs generally escalate to about $16 per cubic yard of soil (measured in situ) because of the general requirements associated with CERCLA site health and safety, and the loss of productivity incurred because of monitoring, use of personal protective gear, and decontamination procedures. Given a soil density of 1.75 tons per cubic yard of in situ soil, the excavation cost is estimated to be $9.10 per ton.

Excavation costs for a vertical-sided shored excavation would be considerably greater. For the excavation to groundwater, costs were assumed to include the material and labor costs associated with a fully-reinforced excavation with dimensions of 120 ft by 120 feet by 53 feet. The total cost would be $2.1 million.

Backfill costs are expected to be $4 per cubic yard of compacted volume, or $2.30 per ton.

4.2.1.3 Treatment Residuals

Alternatives 2 and 3 would result in residual treated soil, including any rocks removed and washed during feed preparation. The treated soil would be analyzed to verify the effectiveness of the treatment in achieving the RAOs and treatment standards, then used to backfill the lagoons. Following this, the disturbed area would be covered with a minimum of 2 feet of clean soil; additional clean fill would be added as necessary to return the area to its natural contours. Finally, the area would be revegetated with native plants.

Replacement of the treated soil in the excavation might be deferred until a groundwater remedy is selected for the site, to facilitate the possible installation of additional wells or implementation of a remedial action. In that case, the treated soil would be stockpiled temporarily in the area of the lagoons. A liner and cover could be used to prevent dispersion of the treated soil. Costs associated with stockpiling the treated soil are not included in the FS, but would be common to both of the alternatives.

Alternatives 2 and 3 might also result in a small amount of washwater if screening for rocks is required. The anticipated volume is sufficiently low that it is expected it could either be added to the incinerator feed or used to maintain moisture levels in the compost windrows, whichever was appropriate. Alternative 2 would also generate a small amount of wastewater and baghouse dust from the air emissions control system. Management of these materials is discussed with other elements of Alternative 2. No additional residues would be treated under Alternative 3.

4.2.1.4 Monitoring and Review

High surface soil concentrations of contaminants would remain under Alternative 1, and low concentrations of contaminants would remain in subsurface soils in all three alternatives. RCRA closure standards for surface impoundments closed with waste left in place require long-term monitoring [40 CFR 264.228(b)]. Although RCRA requirements are only TBC criteria for lagoon soil remediation, monitoring will be continued

as part of the installation-wide RI/FS; long-term monitoring is not specifically costed in the alternatives presented here.

CERCLA requires that if a remedial action is selected that results in contamination remaining at the site, a review of the action must be conducted no less often than every 5 years to assure that human health and the environment are being protected [CERCLA Section 121(c)]. For purposes of this FS, it has been assumed that a 5-year review would be conducted for any remedial alternative selected.

4.2.1.5 Land Use Restrictions

A basic premise guiding remediation at the Explosives Washout Lagoons is that the site will be released in the future for unrestricted residential or light industrial use. Therefore, none of the alternatives include deed restrictions or other administrative limitations on future land use.

4.2.2 Alternative 1: No Action

4.2.2.1 Process Review

According to the NCP, the level of treatment achieved must be compared to the required expenditures of time and materials as an integral portion of the remedy selection process. The No Action alternative serves as a common reference point for

subsequent analysis and comparison with the other alternatives selected for detailed evaluation.

No Action does not mean that the Explosives Washout Lagoons are to be abandoned immediately. The existing security provisions that limit public access would be continued at least until such time as the Army vacates the UMDA facility. Also, as discussed in Chapter 1, contaminated groundwater beneath the lagoons will be addressed by a separate, site-wide RI/FS.

Some natural recovery of the soil would be expected as a result of the natural degradation/transport processes discussed in Section 2.5. Photolysis of the contaminants could occur in exposed surface soils, but this would have little overall impact on recovery. In situ biodegradation might occur, but its success and rate would be severely limited by the lack of sufficient organic material, moisture, and aeration in the soil present at the Explosives Washout Lagoons. The low precipitation rate versus high evapotranspiration rate in northeastern Oregon makes natural in situ soil washing an unfavorable mechanism for removing contaminants from the soil. Therefore, it is expected that natural recovery of the soil would not occur within a reasonable time frame.

4.2.2.2 NCP Criteria Analysis

The degree to which the No Action alternative satisfies the seven threshold and primary balancing criteria of the NCP is summarized in Table 4-1 and discussed below.

Overall Protection of Human Health and the Environment. This alternative does nothing to enhance protection of adjacent communities, the environment, or future land users. The risks posed by the soil, which were judged by EPA as sufficient to warrant inclusion of the Explosives Washout Lagoons on the NPL, would remain at the current level.

The No Action alternative would present only a minimal risk of exposure to UMDA personnel during routine site activities. The site is removed from areas of active use, so direct contact with soils would not be expected. Exposure via the air pathway would be minimal because the explosives have a low volatility, the surface soils at the lagoons are relatively stable with respect to wind erosion, and no excavation projects (other than those associated with remediation) are planned for the lagoons themselves. This alternative would not require any further construction or operation activities.

Compliance With ARARs. This alternative would not comply with either state or federal ARARs regarding soil remediation. The excess cancer risk posed by direct contact with contaminated surface soils currently present at the lagoons is 4.7×10^{-3} (industrial use scenario) and 1.0×10^{-2} (residential use scenario) (Dames & Moore, 1991). These

Table 4-1
Summary of NCP Criteria Evaluation for No Action Alternative

Effectiveness						
Overall Protection	Compliance with ARARs	Long-Term Effectiveness	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Implementability	Cost
Does not enhance protection of human health and environment. Current and future risks related to soil exposure remain essentially unchanged.	Does not comply with remedial requirements of the NCP or the State of Oregon.	Long-term effectiveness not achieved since future human exposure potential and environmental impacts not reduced. Continued potential for leaching of contaminants to groundwater.	No reduction in mobility or volume. Minimal natural reduction in toxicity.	No near-term activities planned at the site so little exposure to workers. Current access restrictions protect public. Continued absence of vegetation at lagoons.	Requires no active implementation. Difficult to justify to regulatory agencies and community.	Essentially zero in near-term. Probable long-term management and monitoring costs.

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Implementability. There is no technical reason that the No Action alternative could not be implemented. The Explosives Washout Lagoons as they now exist place no constraints on UMDA operations.

However, there are two administrative considerations in implementing this alternative. First, it is highly unlikely that the No Action alternative would be acceptable to the regulatory agencies or generate favorable response from the local communities. Second, existing levels of contamination would place restrictions on future land use, a situation that would be contrary to the potential future use for light industry or residential development following UMDA closure.

Cost. The immediate costs for implementing the No Action alterative would be minimal. However, because the site could pose unacceptable risks to future industrial or residential users, the Army might be required to retain ownership of the site and provide long-term monitoring and management. These costs, while potentially substantial, have not been estimated in this FS because of their indefinite nature.

4.2.3 Alternative 2: Rotary Kiln Incineration

Several viable thermal treatment options were screened in Section 3.4.3.9. Although three incinerator designs have been successfully demonstrated for soils treatment, only the rotary kiln design has been applied to the specific contaminants found at the UMDA Explosives Washout Lagoons. Therefore, by convention, the rotary kiln design

was carried through to detailed analysis. Its analysis here does not preclude the potential use of infrared or circulating bed systems, however. Onsite versus offsite incineration would be the preferred option for the reasons presented in Section 3.4.3.9.

4.2.3.1 Process Review

Because of the relatively low volume of soil to be treated, it is assumed that an onsite incinerator would be either a mobile or a transportable unit leased from a vendor, rather than a fixed unit that would remain at UMDA. Performance specifications covering the "turnkey" requirements for the design, installation, start-up, and operation of an onsite incinerator treating explosives-contaminated soils have been developed previously (Roy F. Weston, Inc., 1985). These performance specifications, along with the feasibility study for explosives-contaminated soils at the Louisiana Army Ammunition Plant (IT, 1987) and vendor information, were used as guidelines in developing the rotary kiln incineration alternative for the UMDA site.

Mobile and transportable incineration units are available in a range of sizes with varying feed rates. The optimal size of the incinerator unit would be determined by the mass of soil to be incinerated. Based on previous experience and discussions with vendors, two units are evaluated here. For the two small-tonnage cases (3,700 and 6,800 tons), it is assumed that a mobile incinerator with a nominal feed rate of 4 tons/hour would be used. For the two large-tonnage cases (30,000 and 47,000 tons), it is assumed that a transportable unit with a nominal feed rate of 20 tons/hr would be

used. The operation of the units is similar, and the process description which follows is applicable to both except as noted.

A mobile or transportable refractory-lined rotary kiln incineration system would be comprised of the following units:

- Mechanical feed system
- Primary combustion chamber
- Secondary combustion chamber (afterburner)
- Air pollution control system
- Ash collection system

The configuration of these components is shown in Figure 4-1, and each is described below. The descriptions are intended to be general. Variations in design features are available that would be equally suitable for this application (such as co-current or countercurrent air flow), and discussion of one design does not preclude consideration of others in the remedial design.

Mechanical Feed System. The contaminated soil would be excavated as described in Section 4.2.1.2, then placed on a temporary storage pad in the feed staging area. Little or no drainage from the pile is anticipated given the low moisture content of 5 to 10 percent observed in soil samples from the lagoons (MKES/CH2M HILL, 1992), and the stockpiled soil would be covered to protect it from precipitation and minimize

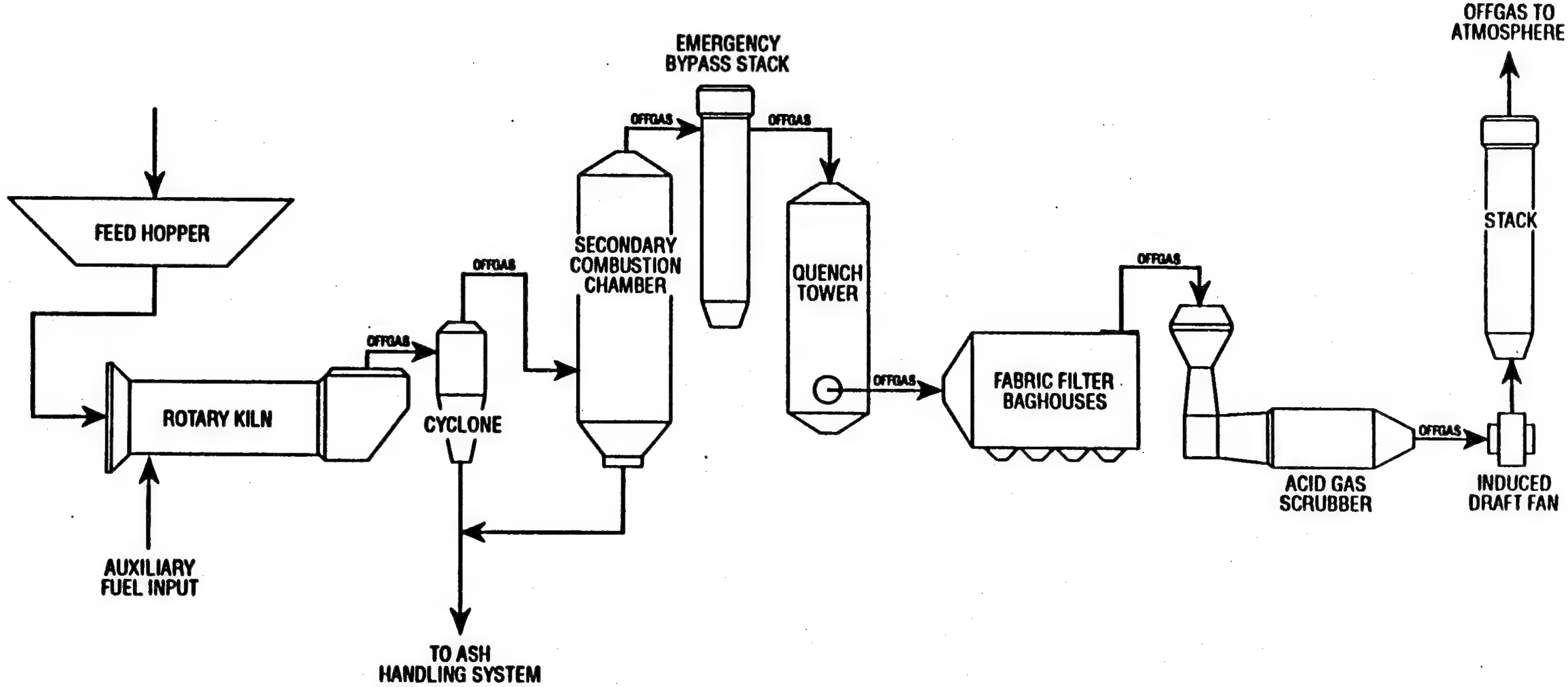

Figure 4-1
TRANSPORTABLE ROTARY KILN SYSTEM

runoff. Any leachate generated would be collected and either added to the incineration feed or transported to UMDA's onsite passive evaporation basins, described in Section 3.4.1.2.

Large rocks and debris might need to be removed from the soil prior to incineration if such artifacts would cause undue stress or damage to the incinerator equipment. The need for and extent of screening would depend on the specific equipment to be used for remediation. For purposes of this FS, it is assumed that the entire volume of soil is passed through an appropriately sized vibrating screen. Since contaminated particulates might adhere to the surface of the rocks, they would then be washed. The volume of washwater generated is expected to be very low compared to the total volume of incinerator feed, and is therefore assumed to be incorporated into the feed.

From the storage pad, the soil would be staged by conveyor belt or other bulk loading equipment to the incinerator feed area. The ideal feed system would eliminate contact or local confinement between the soil and mechanical joints. A typical system would consist of the following three major components (Roy F. Weston, Inc., 1987; Vesta, 1992c):

- A live bottom hopper (e.g., a loading bin with metering screws to control the soil feed rate)

- A system to transfer the soil from the hopper to the kiln feed system (e.g., a twin-screw cross conveyor or weigh belt and drag conveyor)

- A kiln feed system (e.g., a water-jacketed twin-screw feed conveyor or belt conveyor)

Incineration System. The primary combustion chamber is the rotary kiln, a rotatable refractory-brick-lined cylinder mounted at a slight incline to the horizontal. Assuming the rotary kiln is designed for co-current flow, the feed material, primary burner, and combustion air or oxygen all enter at the same end, resulting in co-current flow of ash and combustion gases through the kiln. Rotary kilns with countercurrent design have also been used for explosives-contaminated soils (International Technology, Corp., 1991).

The kiln feed rate, rotation rate, and physical dimensions would be designed and operated to ensure a residence time sufficient to oxidize, paralyze, or vaporize. The kiln and primary burner are typically designed to allow steady-state operation at 1,500 to 1,800°F with a minimum operating temperature of 1,200°F. Ideally, moisture should be maintained below 15 to 18 percent for optimal performance. The mean moisture content in soil samples collected from the lagoons in November 1991 (MKES/CH2M HILL, 1992) was 7 percent.

The kiln generally has a control system that automatically maintains primary combustion chamber temperatures (measured at the outlet end of the kiln) within a preselected control range. The waste feed rate and primary combustion chamber temperature are continuously monitored and recorded. The combustion air inlet ports

and gas flow volumes are typically designed to provide a minimum of 100 percent excess air or oxygen in the primary combustion chamber.

The secondary combustion chamber, or afterburner is a stationary, refractory-lined cylinder. The afterburner design temperature would probably be in the range of 2,300 to 2,400°F, with a minimum of 100 percent excess air. The afterburner configuration and burner orientation are typically designed to provide a high degree of mixing and turbulence. It has a control system that automatically maintains the temperature at the inlet to the off-gas temperature reduction system.

Air Pollution Control (APC). The incinerator APC system is composed of wet and/or dry scrubbing systems designed to remove products of incomplete combustion, particulates, and acid gases from the flue gas exiting the secondary combustion chamber. A heat exchanger can be used between the secondary combustion chamber and the APC equipment to cool the offgas prior to treatment.

An example of a wet scrubbing system would be a venturi scrubber charged with lime or caustic soda; a fabric filter would be an example of a dry scrubbing system. Two or more scrubbing methods are often used in series for high-level treatment. Wet scrubbing systems are typically designed such that blowdown water can be neutralized, filtered, and recycled to the scrubber, minimizing or eliminating wastewater discharges. This is particularly feasible for contaminants that are not halogenated, such as the explosives. If a purge stream is required, it could be directed into the incinerator

combustion chamber or used to support a wet ash collection system. Makeup water requirements are based primarily on evaporative losses. Filtered particulate material from either a wet or dry scrubbing system could be analyzed, and either reincinerated or combined with the treated soil as appropriate. The treated airstream is exhausted through a stack.

It is assumed that any incinerator selected to remediate the explosives-contaminated soil would be equipped with an APC system that would meet local, state, and federal air emissions standards.

Ash Collection System. The solids exiting the primary and secondary combustion chambers are generally referred to as ash. However, because of the low (0.1 to 0.7 percent) total organic carbon concentrations observed in the soil (MKES/CH2M HILL, 1992), the term ash is somewhat misleading. In any case, the treated soil could be collected using a wet ash system, a dry ash system, or a pneumatic ash collection/transportation system. A wet ash system minimizes fugitive dust, and generally employs a closed-loop design so that no liquid discharges from the system. If a dry ash system is used, adequate measures must be taken to minimize fugitive dust emissions.

The treated soil would be discharged from the collection system onto a conveyor. From there, it would be placed in bins, pulled onto a truck, hauled to the storage area, and placed into a covered holding area. Soil samples would then be collected and

analyzed for explosives at a portable onsite laboratory. A similar laboratory was used by IT at the Louisiana Army Ammunition Plant and provided a 24-hour turnaround on analyses (USATHAMA, 1992b). Soil residues that fail to meet any of the treatment requirements would be passed through the incinerator a second time. Soils that meet the requirements would be removed from the holding area and returned to the lagoons to be replaced in the excavation or stockpiled temporarily nearby.

4.2.3.2 Operating Parameters

Site Suitability. The selection of the incineration site would be based on the following criteria:

- The site ideally needs to contain sufficient land area to provide a concentric ring of unoccupied space as a buffer zone between the excavation and incineration areas, and the nearest area of human activity.
- Access roads must be available and capable of supporting the 60,000-lb incinerator trailers and heavy earthmoving equipment.
- Accessibility to the waste feed material must be direct and unencumbered.

A cursory review of site drawings indicates that several locations near the Explosives Washout Lagoons potentially meet the site suitability requirements for onsite incineration.

Topography. The main topographic constraints are susceptibility to flooding, erosion, and offsite drainage runoff. The site must be graded and leveled for equipment placement. Attention should be given to the overall site slope, which should be compatible with the area's natural topographical slope for drainage.

Area Requirements. Sufficient area would be required for the main components of the incineration system and ancillary systems, a feed staging area, and a treated soil stockpile area.

The components of a typical 4-ton-per-hour mobile incinerator are permanently mounted on two over-the-road trailers (Vesta, 1992b). The site design for these trailers, plus the mechanical feed system and all auxiliary equipment and personnel work space, requires a working area of approximately 100 feet by 100 feet (Vesta, 1992c). Half of this area (5,000 ft^2) is assumed to be asphalt pad, and the remainder gravel cover, installed as part of the site preparation.

The components of a typical 20-ton-per-hour transportable unit are transported via 5 to 10 over-the-road trailers (MKES, 1992) and assembled onsite. The main components of the incineration system (combustion chambers, offgas handling system,

control room, and laboratory) require a level working area of approximately 10,000 to 15,000 ft^2, with appropriate concrete foundations and pads, dimensioned according to the layout of the unit and the physical constraints of the site (MKES, 1992). In addition, a graded and graveled area of approximately 10,000 ft^2 is needed for a spare parts trailer, decontamination trailer, and auxiliary equipment.

The contaminated soil stockpile, preparation, and staging area is assumed to be an asphalt pad with curbing. The size required would depend on the manner in which excavation is coordinated with incineration operations. For purposes of the FS, it was considered desirable to provide a surge capacity equal to the average volume of soil that could be processed by the incinerator in 1 week. This would prevent feed availability from limiting incinerator operations and buffer against excavation delays (e.g., inclement weather). Assuming a roughly conical stockpile with a height of 10 feet and continuous incinerator operations, the stockpile area required for the 4-ton-per-hour incinerator and the 20-ton-per-hour incinerator would be 4,000 ft^2 and 19,000 ft^2, respectively. An additional area of 5,000 ft^2 is assumed to be adequate for feed preparation.

The treated soil stockpile area is also assumed to be a curbed asphalt pad. A 2-week capacity would be desirable to provide flexibility in materials handling, accommodate the 24-hour analytical turnaround, and allow for segregation of individually sampled soil piles. The areas required for the 4-ton-per-hour and 20-ton-per-hour incinerators would be 8,000 ft^2 and 38,000 ft^2, respectively.

Temporary covers would be provided for both the contaminated soil and the treated soil stockpiled in the holding area.

Based on the above, the total area requirements are as follows:

- 4-ton-per-hour unit: 27,000 ft^2 (0.6 acre)
- 20-ton-per-hour unit: 87,000 ft^2 (2 acres)

In addition, access roads would be required to connect the treatment area with existing roads and the lagoons.

Utilities. A typical mobile or transportable incinerator unit is designed to be a self-contained and stand-alone unit. Utility requirements include the following:

- A continuous water supply is required to furnish water to the scrubber system, primarily as makeup for evaporative losses. UMDA has indicated that installation hydrant water will be available; if supplies are insufficient, another source, such as water tank trucks, must be used. The water is not required to be potable; however, good quality water is required, low in suspended solids, and not brackish. For a mobile incinerator, evaporative losses are assumed to be 20 gpm; for a transportable unit, they are assumed to be 70 gpm.

- Electrical service of 2,000 kVA, 480 V, and 3 phases is required as the power source for the primary combustion chamber and other large-electric-demand users, such as the ID fan and pumps. In addition, 15 amp, 120-V, 1-phase service is required for ancillary systems and site needs, as required. UMDA has indicated that this service is available in the lagoon area.

- Imported propane equivalent to 6.2 M Btu/hr. (Neither natural gas nor propane service is currently available at UMDA.)

- Water treatment chemicals, as required.

- Fuel oil for feed Btu improvement, as required.

Personnel. The number of operating personnel for a typical mobile incineration unit totals 10 to 15 (Vesta, 1992b) while a larger transportable unit would require a staff of about 40 to 45. These numbers include process operators, supervisors including a shift foreman, a maintenance supervisor, construction operators (as required), administrative staff and a project manager. Operations are conducted in 2 or 3 shifts, 24-hours per day, 7 days per week.

Personnel exposed to contaminated soil are subject to the OSHA requirements for hazardous waste site operations (29 CFR 1910.120), including requirements for

personal protective equipment as dictated by the specific site conditions and contaminants, physical examinations, and hazardous waste site training.

Performance Testing. Waste characterization and treatability testing are necessary to establish the suitability of the contaminated soil feed and the range of recommended operating parameters for the commercial unit to ensure optimum performance within regulatory requirements. The following two test phases would be required for the use of a typical commercial unit at the UMDA site:

- Laboratory analysis of waste feed. Key physical and chemical properties including density, moisture content, heating value, ash content, particle size, elemental composition, metal concentrations, and organic species concentrations would be evaluated.

- Technical evaluation of commercial operation and monitoring for regulatory compliance. As described in Section 3.1, specific operating and emissions standards are stipulated in the ARARs, such as a 99.99 percent DRE for POHCs. Compliance is usually established in a minimum 3-day trial burn prior to or at the beginning of cleanup.

Implementation Time. The time required to implement incineration onsite would depend on the availability of vendor equipment and the time required to complete the procurement process. For purposes of the FS, a time period of one year is assumed to

complete the procurement process and to schedule an incineration system for mobilization. Following that, the time required to mobilize the incinerator onsite (i.e., transport it to the site and prepare it for operation) would depend on the type of unit. The mobilization time for the 4-ton-per-hour system would be approximately 10 days (Vesta, 1992b), while the time required to mobilize a 20-ton-per-hour unit would be 3 to 8 weeks (EPA, 1991). The difference in mobilization times results because the smaller mobile unit remains fixed on the transport trailer, while the larger transportable unit is conveyed as components that must be assembled onsite.

The length of time required to conduct trial burns would be dependent on the requirements of the regulatory agencies. A typical RCRA trial burn would consist of three 4-hour burns. However, agencies might request additional tests based on the results of the initial burns or other considerations. For the purposes of the FS, it is assumed that the trial burn period lasts two weeks, including analytical turnaround time for the samples collected during the burns.

Once trial burns are completed and agency approval is granted, full operation would commence. The operational time required to complete incineration would depend on the soil mass, the feed rate of the incinerator, and the operating efficiency. Maintenance downtimes occur regularly during the course of incinerator operations, and operating efficiencies typically run from 60 to 85 percent (MKES, 1992). For purposes of the FS, an efficiency of 75 percent was assumed. Thus, the average feed rate of the mobile incinerator would be about 3 tons/hr, and the average rate of the transportable

unit would be 15 tons/hr. Assuming a 24-hour-per-day operation 7-days-per-week, incineration times would be as follows:

- 3,700 tons—52 days
- 6,800 tons—95 days
- 30,000 tons—84 days
- 47,000 tons—131 days

4.2.3.3 NCP Criteria Analysis

The seven screening criteria discussed in Section 4.1 are evaluated below.

Overall Protection of Human Health and Environment. Alternative 2 would provide for overall protection of human health and the environment and meet the RAOs set by EPA by destroying essentially all of the contaminants of concern. The concentrations of the explosives in the excavated and treated soil would be reduced approximately 99.99 percent; final concentrations would be below detection limits. The excess cancer risk associated with these concentrations is less than 1×10^{-6} (residential and industrial use scenarios). Explosives concentrations would be below levels at which plant effects are noted.

Near-term protection of the public health and the environment during remediation would be achieved directly by using specific design and operating controls to minimize

emissions and discharges. Indirect protection would also be afforded by the distance from the proposed incinerator to populated areas.

Occupational risks to onsite workers are expected to be minimized through the use of specific operating controls and procedures and appropriate training. Occupational risks would be addressed in the project Health and Safety Plan.

Compliance with ARARs. Incineration would be expected to meet all ARARs, as described below.

Chemical-Specific ARARs. Incineration would be expected to successfully reduce explosives concentrations in the excavated soil to below detection levels. Assuming that nondetection is the reasonable equivalent of background, this would meet the State of Oregon's requirement for cleanup to background concentrations when feasible.

Location-Specific ARARs. Incineration would not be expected to affect protected species present at the UMDA facility, nor affect any offsite designated wetlands.

Action-Specific ARARs. Transportable rotary kiln incineration met all ARARs for the treatment of explosives-contaminated soils at the Cornhusker Army Ammunition Plant and the Louisiana Army Ammunition Plant sites. The requirement of 99.99 percent DRE for each POHC was achieved at both of those sites, where explosives concentrations in the soils were higher than concentrations measured at UMDA.

Provided that the proposed combustion units for UMDA are run in accordance with operational guidelines, the atmospheric dispersion of the stack gases at UMDA would not present a threat to downwind receptors. HCl emissions are not a concern, since chlorine is not a constituent of any site contaminants. Particulate emissions would be controlled with either a single or a multistage scrubbing system. Instrumentation would be provided to monitor the required stack gas parameters.

The rotary kiln incinerator has been demonstrated to treat explosives contaminated soil to the level where the residue can be returned to the excavation site for disposal in accordance with all regulatory and other institutional guidelines (USATHAMA, 1985).

Long-Term Effectiveness and Permanence. Incineration provides for the permanent and irreversible destruction of contaminants, and thus the onsite incineration systems evaluated here are expected to provide long-term protection of human health and the environment. Final explosives concentrations in the incinerated soil would be expected to be below detection limits (less than 1 μg/g). These concentrations are associated with an excess cancer risk of less than 1×10^{-6} (both residential and industrial use scenarios), and are well below levels observed in laboratory studies to cause adverse impacts on vegetation (PNL, 1989; 1990). There would be no permanent disturbance of land areas as part of the remedial project, and the lagoon area would be restored to surrounding conditions following remediation.

Because the destruction of contaminants is essentially 100 percent complete and irreversible, the treated soil would not require long-term management. Evaluation of contaminated groundwater below the lagoon excavation would continue as part of the UMDA installation-wide RI/FS.

Reduction of Toxicity, Mobility, or Volume Through Treatment. Rotary kiln incineration achieves permanent and irreversible reductions in the concentrations of and thus toxicity of the contaminants of concern. The incineration of explosives-contaminated soil in a rotary kiln would destroy virtually all (>99.99 percent) of the toxic contaminants present (USATHAMA, 1985).

Significant volumes of stack gas would be exhausted to the atmosphere, but these emissions are expected to have virtually no adverse impacts because of the use of scrubbing and control systems.

Short-Term Effectiveness. This alternative could be implemented and completed relatively quickly, as discussed in the Section 4.2.3.2. It is assumed that 1 year would be required to determine the required operating parameters and procure the use of a commercially available incineration unit. Following that, onsite mobilization, trial burns, and incinerator operations would require 12 to 18 weeks for scenarios using the mobile incinerator, and 22 to 29 weeks for larger-scale projects using the transportable incinerator.

Short-term impacts to the community, workers, and the environment are expected to be minimal. Access onto the UMDA facility is currently restricted and would remain so throughout the remediation project; therefore, the primary risks associated with incineration would be exposure to the surrounding public and environment from offgas emissions. Typically, the kiln off-gases are routed through an afterburner to complete the combustion process and then scrubbed or filtered to remove acid gases and particulates prior to being exhausted to the atmosphere. Previous applications have demonstrated greater than 99.99 percent destruction efficiency, thus eliminating measurable risks to human health and the environment posed by air-entrained organics (USATHAMA, 1985). Further, the combustion chambers are maintained at slightly negative pressure to avoid leakage of combustion gases. Protection of the community would be achieved by the described design and by close monitoring of incineration and stack gas parameters. In addition, the incinerator would be shut down in the event of an upset.

Protection of workers during excavation and incineration would require special waste handling procedures (e.g., dust control), monitoring, and use of personal protective equipment. A key element of operational safety of the incinerator would be careful control of the combustion process with adequate provisions to prevent the accumulation of pressure. A well-publicized accident did occur at the Cornhusker facility that resulted in serious injury to two operating personnel. The condition leading to the accident, which involved quench tank slagging, was corrected by the contractor.

No protected species or sensitive land areas are expected to be affected during remediation. Land areas disturbed to accommodate incineration operations would be restored following project completion.

Transportation of hazardous materials is not an issue because the incineration unit would be located close to the excavation site and treated soil would remain on the site. Since rotary kiln incineration achieves >99.99 percent destruction of the toxic compounds in the soils, there is very low potential for the exposure of workers and the surrounding community from leakage or other movement of hazardous constituents subsequent to treatment. Full-scale pilot testing on similar soils has shown that the solids may be re-fed to the kiln with waste destruction enhanced on the second pass (IT, 1987). All feed and operational conditions would be fully monitored on a continuous basis, including feed rates, temperatures, pressure, air flow, and stack gas composition.

Implementability. The general technical and administrative feasibility of incinerating soils containing organic explosives has been fully demonstrated at other military installations, such as the Louisiana and Cornhusker Army Ammunition Plants (USATHAMA, 1992a).

Rotary kilns have a relatively high rate of maintenance, but many of the repairs can be done while the unit is on line. The estimated downtime for maintenance is 15 to 40 percent (MKES, 1992). The primary technical concerns associated with this

particular application of incineration are explosives safety with regard to feed delivery to the kiln. To address this, a feed system for explosives-contaminated soils was tested and approved for safe operation (Roy F. Weston, Inc., 1987).

With respect to the specific application of incineration at the UMDA Explosives Washout Lagoons, it would be feasible to assemble the rotary kiln equipment in the project area. No obstacles have been identified in terms of obtaining all normal legal approvals, such as site access authorization and local construction permits. Site access would be granted by UMDA for all required activities. Construction permits would not be required, but all construction would have to meet Army specifications. Special precautions would be taken in design and operation to isolate the incinerator as a potential ignition source from other materials stored at the UMDA facility. Federal, state, and local permits would not be required for this onsite action in accordance with CERCLA Section 121(e) and the FFA, but the system would meet all regulatory requirements with respect to air emissions, water discharges, and solids disposal. Public reaction will be assessed during the public review of the Proposed Plan, and addressed in the development of a Record of Decision.

Availability of mobile and transportable rotary kiln incineration units is good, as this technology is currently seeing widespread use for the treatment of contaminated soils. IT Corporation, Roy F. Weston, Inc., ENRAC, and Vesta are examples of suppliers of mobile and transportable rotary kiln units.

Cost. The costs associated with onsite incineration can be divided into 5 categories as follows:

- Excavation/backfill
- Site preparation
- Mobilization/demobilization
- Site-specific trial burns
- Incinerator operations and maintenance

It is assumed that excavation and backfill would be performed by an outside contractor who would provide all equipment; therefore, all associated costs would be considered operations and maintenance (O&M) costs. Similarly, all incinerator operation costs (including all vendor costs for labor, materials, and use of equipment) are presented as O&M costs. Site preparation, incinerator mobilization, and trial burn costs are presented as capital costs.

Costs were developed based on the process descriptions presented earlier, vendor estimates, and experience at similar sites. They are considered order-of-magnitude estimates and have an expected accuracy within +50 percent and -30 percent as defined by the American Association of Cost Engineers. This range of accuracy is also consistent with current EPA guidance for FS reporting (EPA, 1988b). Costs are summarized by cost category in Table 4-2; the elements of the individual cost categories are discussed below.

Table 4-2
Estimated Costs, Alternative 2, Onsite Incineration

Depth of Excavation	2 Feet	5 Feet	20 Feet	47 Feet
Mass Excavated	3,700 Tons	6,800 Tons	30,000 Tons	47,000 Tons
Capital Costs				
Site Preparation	$350,000[a]	$350,000[a]	$500,000[a]	$500,000[a]
Mobilization/demobilization	$100,000[b]	$100,000[b]	$400,000[a]	$400,000[a]
Trial burns	$200,000[a]	$200,000[a]	$300,000[a]	$300,000[a]
O&M Costs				
Excavation/backfill	$42,200 ($11.40/ton)[a]	$77,500 ($11.40/ton)[a]	$342,000 ($11.40/ton)[a]	$2,200,000[a] ($46.80)[c]
Incinerator Operations	$2,035,000 ($550/ton)[b]	$3,740,000 ($550/ton)[b]	$6,750,000 ($225/ton)	$10,600,000 ($225/ton)
Total	$2,700,000 ($740/ton)	$4,500,000 ($660/ton)	$8,300,000 ($280/ton)	$14,000,000 ($300/ton)[c]

[a]Based on engineering calculations and site experience.
[b]Vesta, 1992a.
[c]Higher unit cost for 47-foot excavation reflects special construction techniques used for vertical-sided excavation.

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Excavation/Backfill. Excavation and backfill costs were presented in Section 4.2.1.2. Based on experience in excavating sandy-gravelly soil at other hazardous waste sites, costs were estimated to be $16 per cubic yard banked soil, or $9.10 per ton. Backfill costs were estimated to be $4 per cubic yard or $2.30 per ton, using both treated soil and clean soil (borrowed from a readily accessible area at UMDA).

Site Preparation. Site preparation includes advance planning and management; detailed site design and development (e.g., access roads, clearing, surface construction); utilities connections; and site support staff.

Area and surface foundation requirements for both a 4-ton-per-hour incinerator system and a 20-ton-per-hour incinerator system were described in Section 4.2.3.2. The required area would be cleared of existing vegetation, surveyed, graded, and compacted. Concrete or asphalt pads would be prepared to support primary incineration equipment as appropriate. Asphalt pads with temporary covers would be constructed as stockpile areas for contaminated soil and treated soil. Graded and graveled areas would be constructed for auxiliary equipment (e.g., vehicle storage, personnel trailers). Gravel roads sufficiently wide to accommodate incineration trailers and construction equipment would be installed between existing roads, the lagoons, and the incinerator area.

Electrical cable and appropriate auxiliary equipment would be installed to tie in to the existing UMDA power supply. Temporary piping would be installed to provide water service from the UMDA hydrant system to the incinerator scrubbing system. Outdoor lighting would be installed as necessary to accommodate 24-hour-per-day operations.

Total costs for site preparation for the 20-ton-per-hour unit are estimated at $500,000, based on engineering calculations and experience at comparable sites. Because of the smaller area and less substantial foundation requirements, costs are estimated to be somewhat less for the 4-ton-per-hour unit, at $350,000.

Mobilization/Demobilization. Mobilization/demobilization costs are generally a lump sum charged by the vendor. Mobilization includes transportation to the site, setup and assembly as required, and system checkout to ensure proper operation. Demobilization includes decontamination of the incinerator, disassembly as necessary, and transport offsite.

Vesta Technology, Inc. (1992b) estimated total mobilization/demobilization costs for their 4-ton-per-hour incinerator at $100,000. This included an estimated 6 to 7 days to transport the incinerator to the UMDA and 2 to 3 days to set up the components, which remain on the trailers. Based on experience at other sites, mobilization/demobilization costs for a 20-ton-per-hour incinerator were estimated to be $400,000 (MKES, 1992). Costs are higher because the incinerator components must be assembled onsite; mobilization times are typically 3 to 8 weeks (EPA, 1991d).

Trial burns. Regulatory agencies typically require trial burns to establish the incinerator operating conditions required to achieve compliance with performance standards. The complexity of the trial burn depends on the nature of the waste to be incinerated. Incineration of explosives-contaminated soil is expected to be relatively straightforward because of the absence of heavy metals and halogenated compounds, constituents which can require more extensive evaluation of air pollution control equipment. For complex sites, trial burn costs including all regulatory negotiations can be as high as $500,000 (IT, 1992).

Based on experience at other sites, trial burn costs for remdiating the UMDA lagoons using a transportable 20-ton-per-hour unit were estimated to be up to $300,000 (MKES, 1992). Separate trial burn costs were not provided for the mobile 4-ton-per-hour unit. For purposes of this FS, it was assumed that trial burn costs for the mobile unit would be only slightly less, at $200,000. In each case, the cost includes expenses associated with initial feed characterization; analysis of treated soil generated during the trial burns; air quality monitoring and emissions analysis; operation and maintenance of the incinerator; and meetings with regulatory agencies.

Operations/Maintenance. Operations and maintenance (O&M) costs include all on-stream costs charged by the vendor for the labor, equipment, supplies, and vendor-supplied utilities associated with feed preparation and operation of the incinerator. Onstream costs are generally quoted as a cost per day or a cost per ton of feed or ash. The vendor will generally include his overhead costs such as insurance, taxes, and

4.2.3.4 Summary

A compilation of the NCP criteria evaluation is provided in Table 4-3. Based on the evaluation, incineration appears to be an effective and feasible technique for remediating the UMDA Explosives Washout Lagoons.

The unit cost, including excavation and materials handling, could range from about \$200 to 300 per ton for a high-tonnage scenario using a transportable incinerator to \$660 to 740 per ton for a low-tonnage scenario using a mobile incinerator. A review of previous projects where explosives-contaminated soils were incinerated is provided in Table 4-4. Estimated costs calculated in this FS and actual costs incurred during similar past and ongoing projects are similar, thus supporting the independently derived estimates.

4.2.4 Alternative 3: Composting

Three potential composting methods were screened in Section 3.4.3.10: static pile, windrow, and Mechanically Agitated In-Vessel (MAIV). Treatability studies indicate that the MAIV system is substantially more effective than static pile composting (Roy F. Weston, Inc., 1991a), so the MAIV was selected for further evaluation here. In addition, a process optimization study using windrows is currently underway. Based on the judgment of the investigators, the effectiveness of windrow composting is expected to

Table 4-3
Summary of NCP Criteria Evaluation for Onsite Rotary Kiln Incineration Alternative

Effectiveness						
Overall Protection	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction of Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Implementability**	**Cost**
Protection of human health achieved by reduction of excess cancer risk to 1×10^{-6} (residential use scenario), and by treatment and monitoring of incineration stack gas emissions. Environment protected by reducing explosives concentrations to levels to below those that cause significant plant stress.	Accomplished with >99.99 percent DRE of explosives and testing of treated soil before backfilling lagoons.	Effectiveness is permanent and long term, since contaminants are destroyed with a 99.99% efficiency. No long-term management required.	Destruction of contaminants reduces toxicity associated with explosives to essentially zero. Stack emissions expected to be very low toxicity. Treated soil not expected to be hazardous.	Workers, environment, and community protected during operations by using proper safety procedures and process monitoring. Time to implement and complete remediation 15 to 19 months.	Mobile and transportable rotary kiln incinerators are readily available and have been used at other explosives-contaminated soil sites.	2-ft. excavation: $2,730,000 5-ft. excavation: $4,470,000 20-ft. excavation: $8,290,000 47-ft. excavation: $14,000,000

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be comparable to the MAIV at a considerably lower cost (Roy F. Weston, Inc. 1991b). Therefore, it is also evaluated here.

Table 4-4
Incineration Projects Applied to Explosives-Contaminated Soils

Site	Date of Remedial Action	Cost	Total Soil Treated
Cornhusker Army Ammunition Plant	1987-1988	$260/ton	40,000 tons
Louisiana Army Ammunition Plant	1988-1990	$330/ton	102,000 tons
Savanna Army Depot	Ongoing	$350/ton (estimated)	25,000 tons (estimated)

From USATHAMA, 1992a.

4.2.4.1 Process Review

The conceptual process descriptions which follow address the system components and operations required to complete remediation using composting. Table 4-5 lists the major system components and Figure 4-2 presents a schematic flow of operations for both the windrow and MAIV systems. The details included in the process descriptions might be refined during remedial design, but the basic processing operations would remain the same. The primary difference between the two composting technologies is the method used to maintain optimal conditions for composting within the material piles. The more automated MAIV system would be more costly, requiring higher

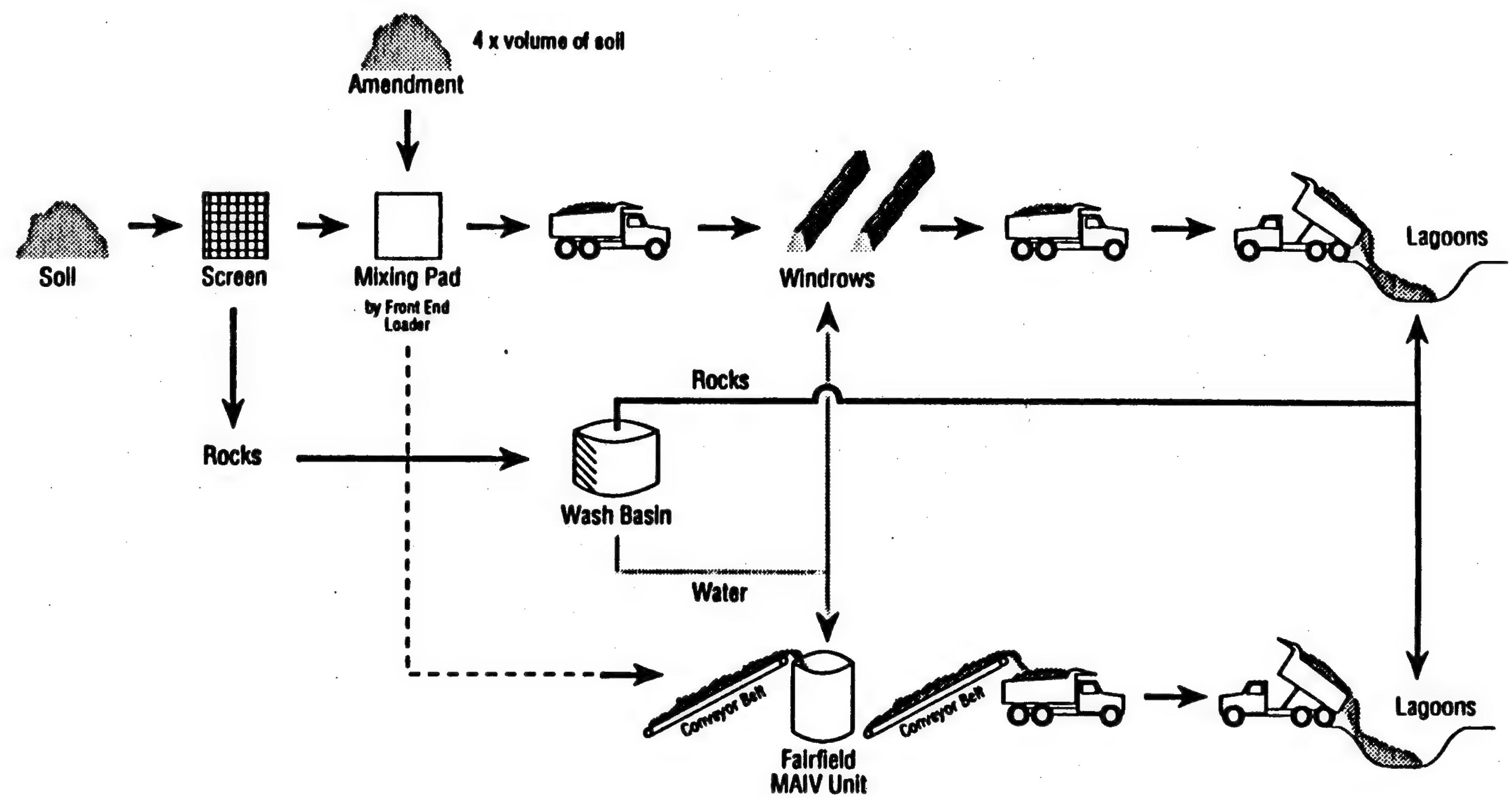

Figure 4-2
Composting System
Process Flow

capital, operating, and maintenance costs than the windrow system, but provides for a higher level of process control and greater ease in achieving effective contaminant degradation.

Table 4-5 Composting System Components	
Common Facilities	Material storage area Soil screen Mixing area Process water system Maintenance shop, administrative and personnel spaces Equipment: front-end loader, dump truck
Windrow System	Windrow pad, asphalt Windrow-turning machine Sprung instant structures to cover pad (4)
MAIV System	MAIV unit Conveyor feed and discharge beltlines Forced-air aeration system Emergency generator

Excavation, Materials Handling, and Compost Preparation. The activities involving excavation and compost preparation would be common to both the MAIV and windrow systems. The contaminated soil would be excavated as described in Section 4.2.1.2. Large rocks and debris might need to be removed from the soil prior to composting if such artifacts would cause undue stress or damage to the windrow turner or the MAIV equipment. The need for and extent of screening would depend on the specific technology and equipment to be used for remediation. For purposes of this FS, it is assumed that the entire volume of soil is passed through an appropriate

sized vibrating screen. Since contaminated particulates might adhere to the surface of the rocks, they would then be washed. The washwater generated could be used to help maintain the compost moisture content, and therefore treatment of the water would not be required. The screened soil would then be placed in the mixing area.

The mixing area would consist of four open-top, three-sided concrete bins. Three of these would be used to mix soil and amendment. The fourth would be used to receive and temporarily store the organic amendment that would be delivered daily.

Three amendment compositions, developed on the basis of materials available in the region around UMDA, were evaluated during the composting optimization study described in Section 3.4.3.10. In general, amendment compositions B and C, which incorporate horse and cow manure respectively, appeared to be substantially more effective at reducing explosives concentrations than amendment A, which contained chicken manure (Roy F. Weston, Inc., 1991a). Since amendment C is substantially less expensive than amendment B, it is assumed for the purposes of the FS that amendment C would be used for full-scale composting. The use of amendment B would not be expected to affect the evaluation of composting effectiveness but could influence overall cost.

The most effective soil loading volume as a percent of total compost volume appeared to be between 10 and 25 percent (Roy F. Weston, 1991a). Greater volume loadings significantly reduced the degradation potential of the explosives, probably because a

high soil loading inhibits self-heating. For the development of costs and operating parameters in the FS, a soil loading of 20 percent is assumed. The soil loading has the single largest effect on the economics of the composting system. Because the soil is a minority fraction, changes in loading greatly influence the volume of amendment required, the size of the facility necessary to process the compost mixture, and the remediation period.

An ongoing study using windrows will be used to further refine and select the amendment parameters prior to full-scale implementation (Roy F. Weston, Inc., 1992).

A volume of screened soil would be placed into one of the mixing bins, four volumes of amendment would be added, and the materials would be combined using a front-end loader. Multiple mixing bins would allow for a completed batch to be removed from one bin while mixing is being done in a second and screened soil is being added to a third. The mixed batches would be loaded into a dump truck and delivered to either the MAIV facility or the windrow pad area. At the MAIV facility, the mixture would be deposited into a feeding bin to be charged to the MAIV vessel using either a belt or auger system. At the windrow pad area, a front-end loader would be used to form the mixture into a windrow on the pad.

For purposes of the FS, it is assumed that soil excavation and compost preparation would be performed five days per week, and that a total of 100 cubic yards of soil/amendment mix would be prepared each of those days.

MAIV. The following description of MAIV composting was based on a semicontinuous system designed and built by the Fairfield Service Co., Marion, Ohio. The Fairfield MAIV was selected because a pilot-scale Fairfield system was used in the UMDA composting optimization study. The results of that study indicated that explosives were effectively degraded over a period of 20 days using MAIV composting (Roy F. Weston, Inc., 1991a). Based on those data, 3 weeks' residence time was assumed to be adequate and was used to size equipment and facilities for this analysis. Consideration here of the Fairfield MAIV does not preclude the use of other similar systems.

The Fairfield MAIV system evaluated here consists of an 80-foot-diameter concrete reactor vessel, 10 feet deep and covered with a fiberglass dome. The reactor holds approximately 1,860 cubic yards of material, sufficient for the 1,500 cubic yards of compost that would be prepared over 15 working days, with a 20 percent overflow capacity. Figure 4-3 shows a schematic of such a vessel. The reactor would be charged each working day from the top by a movable auger-fed chute or conveyor belt. Commencing 3 weeks after the initial charge, material would be discharged daily through a port in the bottom of the reactor and conveyed via auger and pipe to a dump truck to be returned to the lagoons and replaced in the excavation.

The Fairfield MAIV reactor employs a unique concept in mixing the compost with screw augers suspended from a traveling bridge that rotates around the top of the reactor. The augers spin, thus aerating and mixing the compost and moving the material from the periphery to the center. The reactor is divided into five distinct aeration

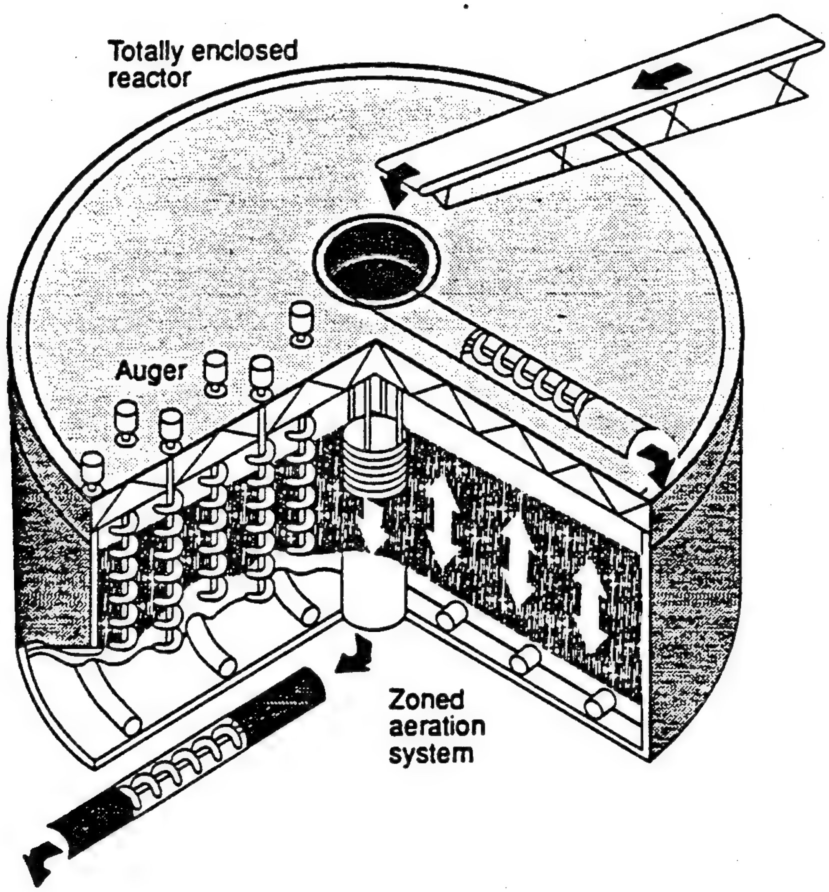

Figure 4-3
FAIRFIELD COMPOST SYSTEM

zones, which are concentric rings that correspond to the travel path of the composted material (top outer to bottom center of reactor). By varying aeration rates across the separate zones, the aeration demands of the system can be matched more closely, thus maintaining more controlled and uniform moisture and temperature profiles within the compost. Air and water are added to the reactor as needed via a manifold.

The Fairfield MAIV would be equipped with a process control system to guide mixing and aeration and an offgas control system. Following processing, the compost would be discharged through the bottom and conveyed by belt or auger to the treated soil stockpile area for sampling.

A Fairfield system with a similar capacity has been operating since 1986 in Plattsburg, New York. The Plattsburg unit processes about 22 tons/day (dry weight) of dewatered wastewater sludges plus amendment (CH2M HILL, 1989). The most notable problems with the Plattsburg system have included corrosion and odor. However, both of these issues are thought to be associated with the characteristics of the sludge and are unlikely to be significant with the UMDA soil.

Total O&M costs at Plattsburg have averaged an estimated $1 million annually, which includes annual odor control chemical costs of $100,000. A staff of six operates the system in two shifts daily: day shift and swing shift. The owner has a service and maintenance contract with the manufacturer who makes regular visits to the facility as well as providing demand maintenance support as necessary.

Windrows. The following conceptual description of windrow composting was based on discussions with USATHAMA (USATHAMA, 1991b) and Roy F. Weston, Inc. (1991b). The size and operating parameters of an actual facility might be modified based on the results of the windrow composting optimization study and the desired remediation time.

The primary design parameter is the assumption that a composting period of 45 days would be required to degrade explosives to acceptable levels using windrows. This period was based on consideration of the aerated static pile studies and MAIV studies performed as part of the composting optimization study (Roy F. Weston, Inc., 1991a) and the assumption that the rate of windrow composting would be somewhat slower than MAIV composting because of a lower level of process control. A longer composting period could be required from November through March because of low ambient air temperatures.

For purposes of costing this alternative, it was assumed that four 60-foot by 210-foot temporary buildings would be erected on a single asphalt pad. Each building would be capable of enclosing two 150-foot-long windrows, with room available to maneuver a mechanical windrow machine. Sprung structures, consisting of an external frame with plastic tensioned between the bars of the frame, would be suitable for this application. The primary benefits to covering the windrows are:

- Reduce dispersion of material due to wind erosion

- Minimize leachate by eliminating direct precipitation and stormwater runon

- Better control of temperature and moisture by reducing air exchange with the external atmosphere

The windrow system is less process intensive than the MAIV system. Each working day, a new batch of compost mixture would be either used to start a new windrow or added as a new segment to an existing windrow. The windrow machine would then pass over the new compost to fluff it, aerate it, and establish the windrow. Once established, a windrow would need to be turned periodically by the windrow turning machine. (The optimum turning period in terms of balancing temperature control and aeration is currently being studied.) At the third or fourth week, the volume of the windrow would be reduced by microbial activity so the windrow could be consolidated using a front-end loader. After a given windrow segment had composted for 45 days (7 weeks), it would be sampled to verify that remedial performance standards were met. If so, the compost would be loaded into a dump truck and returned to the lagoons for replacement in the excavation.

Aeration for the compost matrix is provided by the windrow-turning machine. This is assumed to be a self-propelled machine using a rotating drum with multiple short blades. As the machine moves along the windrow, the drum cuts into it, macerating and fluffing the material, which allows air to be introduced into the compost matrix.

This process increases the volume of the windrow by approximately 20 percent, admitting an excess amount of oxygen to maintain microbial activity but releasing heat and water vapor.

The loss of heat and water can adversely affect the activity of the microbial populations. Covering the windrows with something like the Sprung structures will help reduce heat loss by maintaining a more uniform air temperature in the immediate vicinity of the material. In addition, the ongoing windrow optimization study includes evaluating windrow turning machines and turning periods that minimize temperature fluctuations. To combat moisture loss, water is assumed to be added to the windrows as needed.

Compost Disposition. The compost periods assumed for both the MAIV and the windrow systems were developed based on the remedial goals for the project, i.e., reducing explosives concentrations to levels that are protective of human health and the environment. It is anticipated that a compost period of up to 45 days would be required to meet these goals. As described in Section 4.2.1.3, the compost could be replaced in the lagoon excavation when the remedial goals are achieved.

Many of the materials in the compost amendment, such as the manure, would be expected to decompose within the same 45-day period. However, some of the components in the amendment, particularly vegetable matter such as straw, are more difficult to decompose because of lignins and will continue to do so beyond the initial 45 days.

This phase of composting is referred to as "curing," and results in the production of stabilized compost. (Stabilized compost requires no additional nutrients and has a low oxygen demand.) While curing would be enhanced by active compost management, such as would occur in the windrows or MAIV, it will also proceed, but more slowly, if the compost is not actively managed and the treated soil is replaced into the ground.

State solid waste regulations specify the acceptable quality of finished product when composting wastewater sludges, yard wastes, or municipal solid wastes, because the product could be made available to the public immediately. Regulatory acceptance would normally require curing. However, the goals of the UMDA composting project are not comparable to the goals for typical composting facilities. In addition, the probability of public exposure to the compost material is low for at least the next several years. Therefore, it is assumed that a 45-day compost period followed by replacement of the treated soil into the lagoon excavation would be acceptable.

4.2.4.2 Operating Parameters

Site Suitability. The selection of the material processing and compost treatment site is based on the following criteria:

- The site ideally needs to contain sufficient land area to provide a concentric ring of unoccupied space as a buffer zone between active storage, treatment, and disposal areas, and the nearest area of human activity.

- Access roads must be available and capable of supporting the 60,000-lb and heavy earthmoving equipment.

- Accessibility to the waste feed material must be direct and unencumbered, with adequate feed preparation areas.

A cursory review of site drawings indicates that several locations near the Explosives Washout Lagoons site meet potentially the site suitability requirements for development of a composting facility.

Topographic Constraints. The main topographic constraints are susceptibility to flooding, erosion, and offsite drainage runoff. The site must be graded and leveled for equipment placement. Attention should be given to the overall site slope, which should be compatible with the area's natural topographical slope for drainage.

Site Area Requirements. The site would require approximately 7 acres to provide adequate room for vehicle access and maneuvering; storage areas for contaminated soil, amendment, and treated soil; a mixing area, and the windrow pad. In addition, an access road would be required to connect with the existing roads and to the lagoon area itself.

For the 3,700-ton and 6,800-ton soil treatment cases, the windrows are assumed to be assembled on an asphalt foundation inside four Sprung structures, each of which is

60 feet by 210 feet. With allowances for room to maneuver the mechanical windrow turner between the structures and around the perimeter, the total area required for the windrows would be about 80,000 ft^2.

The contaminated soil stockpile, preparation, and staging area are assumed to require a curbed asphalt-paved area of 30,000 ft^2, allowing for a 3-day stockpile of amendment (240 cubic yards), a 1-week stockpile of excavated soil (100 cubic yards), and three 3-sided mixing bins. The 1-week stockpile capacity for excavated soil would prevent feed availability from limiting the preparation of compost in the event of excavation delays.

The treated compost stockpile area is also assumed to be a curbed asphalt pad. A two-week storage capacity would be provided to allow for flexibility in materials handling and to accommodate the 24-hour analytical turnaround for performance verification sampling. The area required would be about 5000 ft^2, assuming that the volume of the final compost is approximately twice the volume of the initial soil added (the amendment compacts during composting.)

Additional graded and graveled areas are needed for vehicle access, administrative and personnel facilities, maintenance areas, and the onsite portable laboratory. The additional area required is assumed to be about 2 acres.

Based on the above, the total area requirement for the 3,700- to 6,800-ton composting facility is about 5 acres. The required area would be double for a facility designed to process 30,000 tons of contaminated soil. In addition to these areas, access roads would be required to connect the treatment area with existing roads and the lagoons.

Utilities. Common utilities requirements for either the windrow or Fairfield system include:

- A continuous water supply is required to provide moisture for the compost mixture. UMDA has indicated that hydrant water will be available; if supplies are insufficient and facility water is not available, a water tank truck could be brought on the site. The water for the compost system is not required to be potable. Total demand for process water is estimated to be from 5 to 8 gallons per minute. In addition, sufficient water pressure must be available to support the fire protection system typically required for composting facilities.

- Electrical service of 220/440-V sufficient for a normal equipment maintenance facility is required. This should be sufficient to provide 200-ampere, 120-V, 1-phase service for the administrative and personnel spaces.

In addition, the Fairfield MAIV unit would require 480-V, 270-kVA electrical service to provide sufficient power to satisfy the 327-hp demand when feeding and discharging.

Personnel. Operating personnel for a typical MAIV unit total 8 to 11. This includes equipment operators, an operations supervisor, a maintenance supervisor/mechanic, an office administrator/clerk, and a project manager. Although the compost matrix is active 24 hours per day, 7 days per week, the operations schedule typically consists of one 8-hour shift per day, 5 days per week.

Six operating personnel would be required for windrow composting. This would include three equipment operators to handle the windrow machine, front-end loader, and dump truck, a maintenance supervisor, a project supervisor, and an administrative assistant/clerk. The operations schedule would typically consist of 8-hour shifts, 5 days per week.

Personnel exposed to contaminated soil are subjected to the OSHA requirements for hazardous waste site operations (29 CFR 1910-120), including requirements for personal protective equipment (as dictated by the specific site conditions and contaminants), physical examinations, and hazardous waste site training.

Laboratory Analysis of Waste Feed. Laboratory analyses for the following key physical and chemical properties of the contaminated soil and the compost matrix prior to composting are desirable:

- Density—to determine amendment mixing ratio, compost processing time, and handling requirements

- Moisture content—to determine additional moisture requirements

- Explosives species and concentrations—to determine personnel protection needs and to provide a baseline for evaluating the effectiveness of treatment.

Following composting, the compost matrix would again be analyzed for explosives species and concentrations to verify that the remediation criteria were met.

Treatability Testing. Treatability testing and optimization using windrows is currently being completed at UMDA. At the completion of that study, additional data will be available to refine soil-to-amendment ratios, water requirements, and processing times. These data will be essential in developing the design parameters for a final treatment facility design.

Implementation Time. The time required to implement composting onsite would depend on the progress of windrow testing and time required for the procurement process, activities that are assumed to proceed concurrently. For purposes of the FS, a time period of one year is assumed to complete these activities and prepare the site for composting. Following that, full operation would commence. The operational time

required to complete composting would depend on the soil mass and the type of composting system used. The MAIV system described has a charge rate of 20 cubic yards of loose soil per day, 5 days per week, and requires a residence time of 3 weeks. The windrow system for the two smaller-tonnage scenarios would have a charge rate of 20 cubic yards of loose soil per day, 5 days per week, and a residence time of 7 weeks. The windrow system for a larger-tonnage case would have a charge rate of 40 cubic yards per day. Allowing for the residence time for the last batch charged to either system, the total period of composting operations would be as follows:

- 3,700 tons—28 weeks (MAIV); 32 weeks (windrow)
- 6,800 tons—50 weeks (MAIV); 54 weeks (windrow)
- 30,000 tons—208 weeks (MAIV); 109 weeks (windrow)

4.2.4.3 NCP Criteria Analysis

The seven screening criteria discussed in Section 4.1 are evaluated below.

Overall Protection of Human Health and Environment. This alternative would provide for the overall protection of human health and the environment by reducing TNT and RDX concentrations in the finished compost to 30 µg/g or less each. Assuming an average 2,4-DNT concentration of 1 µg/g based on initial soil concentrations, the resulting excess cancer risk would be 7.2×10^{-6} (light industrial use) and 1.8×10^{-5} (residential use). In addition, the plant stress associated with very high explosives

concentrations would be greatly reduced. However, laboratory studies indicate there might still be some stunting of plant height at concentrations of 30 μg/g (PNL, 1989; 1990).

Near-term protection of the public health and the environment during remediation would be achieved directly by using specific design and operating controls. Indirect protection would also be afforded by the distance from the proposed composting facility to populated areas.

Occupational risks to onsite workers are expected to be minimal and would be addressed in the project Health and Safety Plan.

Compliance with ARARs. It appears that composting would meet all ARARs.

Chemical-Specific ARARs. Composting would not be expected to reduce explosives concentrations in the excavated soil to background (below detection) levels. However, it would be expected to reduce explosives concentrations to levels that are within the acceptable range of 1×10^{-4} to 1×10^{-6} for excess cancer risk.

In accordance with the State of Oregon's requirement, a cost-benefit analysis is provided in Section 4.3.

Location-Specific ARARs. Composting is not expected to affect protected species on the UMDA facility, nor is it expected to affect offsite designated wetlands.

Action-Specific ARARs. ARARs that must be addressed in evaluating a composting alternative were discussed in Section 3.1. All of these would be met by the proposed facility design and operation. The ARARs include these special rules under Oregon's state solid waste regulations:

- Facilities shall be designed and planned to handle the non-compostable material generated by the materials processing.

- The facility shall be designed and operated to minimize odors and shall not be sited in odor-sensitive areas.

- Physical design requirements such as access roads, drainage, fire protection, fences, truck-washing facilities, sewage disposal shall be provided to the satisfaction of ODEQ.

- A solid waste handling plan shall be written to address the disposal of the compost material.

The proposed facility layout for both composting systems includes all of the state-mandated design features. Fugitive dust and odor emissions will be controlled through the

application of water while turning the windrows and in the facility design of the MAIV. The remote location of the facility would limit the impact of odors and dust to offsite populations.

A site-specific composting optimization study has indicated that explosives concentrations in composted soils are reduced to levels that meet the remedial action goals and allow the compost residue to be replaced in the lagoon excavation in accordance with all regulatory guidelines (Roy F. Weston, Inc., 1991a).

Long-Term Effectiveness and Permanence. Composting is expected to reduce explosives concentrations in excavated soil to levels that protect human health and the environment and that require no additional long-term controls. The degree of explosives degradation provided by composting is expected to result in residual TNT and RDX concentrations not exceeding 30 μg/g each. The total excess cancer risk associated with these concentrations is 4.5×10^{-6} (industrial use scenario) and 1.2×10^{-5} (residential use scenario).

2,4-DNT was not specifically evaluated in composting studies, although laboratory studies indicate that it would be susceptible to biodegradation under composting conditions (Dames & Moore, 1991). One reason 2,4-DNT was excluded from study was that its already low concentrations make evaluation difficult; concentrations are generally below detection limits (0.424 μg/g) in the top 8 feet of soil, and average 1 μg/g below that. If 2,4-DNT at a concentration of 1 μg/g is included in the total excess cancer risk

calculations, the total excess cancer risk from the composted soil would be 7.2×10^{-6} (industrial use scenario) and 1.8×10^{-5} (residential use scenario).

The biodegradation process is not entirely understood, but studies indicate that the observed reductions in explosives concentrations would be permanent. In soil, compost, and water, TNT appears to biotransform rapidly into amine metabolites (Dames & Moore, 1991). A similar transformation process appears to occur following the absorption of TNT through the root systems of plants (PNL, 1989). When sufficient organic material is present (as in compost), the metabolites then appear to become covalently bonded to the insoluble macromolecules in the humus and biomass (Dames & Moore, 1991). Although humus itself will eventually degrade, the mechanisms are such that the TNT metabolites would be expected to remain incorporated in fragments of humus and absorbed and degraded by the microbial population (Dames & Moore, 1991). Studies of RDX and 2,4-DNT variously indicate that they also undergo a process of incorporation into humus, or that they are completely degraded, depending upon the bacterial population and nutrient augmentation (Dames & Moore, 1991).

Because the reduction in explosives concentrations is expected to be permanent and the compost itself contains only native microorganisms, the treated soil would not require long-term management. Evaluation of contaminated groundwater below the lagoon excavation would continue as part of the UMDA installation-wide RI/FS.

There would be no permanent disturbance of land areas as part of the remedial project, and the lagoon area would be restored to surrounding conditions following remediation.

Reduction of Toxicity, Mobility, or Volume Through Treatment. As discussed in Section 3.4.3.10, extractable concentrations of the explosives decrease by greater than 90 percent after composting. In addition, toxicological studies conducted by Oak Ridge National Laboratory indicate that, given appropriate composting conditions, the aquatic toxicity of the soil can be reduced by 88 percent and bacterial mutagenicity by 98 percent (ORNL, 1991b).

Numeric results of these studies are summarized in Table 4-6 and discussed below.

The toxicological studies were conducted using samples of the finished compost produced during the composting optimization study. Study elements included:

- An analysis for contaminants and TNT metabolites (amine degradation products)

- Ames bacterial mutagenicity tests (using acetonitrile extracts of the compost)

- Acute and chronic toxicity tests using the aquatic crustaceans *Ceridaphnia dubia* (using leachate derived from the compost)

- A rat oral toxicity screen, using a single 1-gram dose of compost and a 14-day observation period

As seen in the table, results vary depending on soil loading and amendment composition. Given soil loadings of less than 30 percent, bacterial mutagenicity consistently decreases by greater than 90 percent regardless of amendment composition. A soil loading of 25 percent in composition with a cow manure-based amendment reduced aquatic toxicity by 88 percent.

Based on these studies, ORNL concluded that composting can effectively reduce the explosives concentrations and bacterial mutagenicity in explosives-contaminated soil and can reduce the aquatic toxicity. Leachate toxicity to humans was evaluated by comparing leachate concentrations of TNT, RDX, and HMX with 100 times their EPA Drinking Water Equivalent levels. The factor of 100 is a conservative estimate of the soil-groundwater system dilution factor (ORNL, 1991b). The concentrations in the leachate from finished compost were below this criterion, indicating that toxicity to humans would not be expected.

ORNL noted in their summary that low levels of explosives and metabolites, bacterial mutagenicity, and leachable toxicity remain after composting; but these did not appear

to present a serious health concern. In fact, no mortality or toxic effects from finished compost were observed in a rat oral toxicity screen.

Short-Term Effectiveness. If selected as the remedial action, composting could be implemented in approximately 1 year. Following that, the desired clean-up levels could be achieved in about 8 months for a 2-foot excavation and 12 months for a 5-foot excavation. These scenarios would use the same size facility and equipment. A facility with over double the capacity would be constructed for a 20-foot excavation; the projected volume of soil could then be composted in 25 months.

This alternative poses little risk to the community, workers, or the environment during its implementation. The remote location on a secured military facility would minimize unauthorized public access to the site, and the distance from the Explosives Washout Lagoons to the UMDA facility boundary would provide adequate dispersal of any odors and airborne contaminants. The microorganisms used for composting are native and are not expected to present health risks to the public.

There is also minimal risk to the workers involved in this operation. Workers would be protected from exposure to contaminants through special waste handling procedures (e.g., dust control), monitoring, and use of appropriate protective gear.

No protected species or sensitive land areas are expected to be affected during remediation. Land areas disturbed to accommodate composting operations would be restored

following project completion. Composting is not a water-intensive treatment method, so the impact on regional water supplies would be minimal.

Implementability. The general technical feasibility of composting soils containing organic explosives has been demonstrated on a pilot scale at UMDA. The process to be employed at UMDA involves the composting of agricultural waste (manure, vegetable wastes, and bulking agents) and codegradation of the explosives by the microbial populations. Composting of agricultural wastes is a well developed technology used throughout the country. Construction of the windrow composting facility poses no unusual design or construction problems, and windrow composting operations do not require unusual skills or knowledge. A large body of knowledge exists on the methods and techniques that are effective in controlling the composting matrix environment. MAIV composting is somewhat more complex, but has been employed successfully elsewhere as described in Section 4.2.4.1.

Administratively, composting of explosives-contaminated soil is supported by EPA as a potentially viable innovative technology. It is expected to require little administrative effort to implement.

Cost. The costs associated with the composting system options have been subdivided into three categories as follows:

- Excavation/backfilling

- Site and facility preparation
- Compost facility operations and maintenance (O&M)

All site and facility preparation costs, including procurement of equipment items, are considered capital costs. It is assumed that excavation and backfill would be performed by an outside contractor who would provide all associated equipment, so this cost element is assumed to be entirely O&M. All costs to operate and maintain the compost facility once operations are initiated are assumed to be O&M.

Costs were developed based on the process descriptions for both windrow and MAIV composting presented earlier. They are considered order-of-magnitude estimates and have an expected accuracy within +50 percent and -30 percent as defined by the American Association of Cost Engineers. This range of accuracy is also consistent with current EPA guidance for FS reporting (EPA, 1988b). Costs are summarized by cost category in Table 4-7; the elements of the individual cost categories are discussed below.

Excavation/Backfill. Excavation and backfill costs were presented in Section 4.2.1.2. Based on experience in excavating sandy-gravelly soil at other hazardous waste sites, costs were estimated to be $16 per cubic yard of soil measured in situ, or $9.10 per ton. Backfill costs were estimated to be $4 per cubic yard or $2.30 per ton, using treated soil as available and clean soil borrowed from a readily accessible area at UMDA.

Table 4-7 Estimated Costs, Alternative 3, Onsite Composting			
Depth of Excavation Tons of Soil	**2 Feet 3,700**	**5 Feet[a] 6,800**	**20 Feet 30,000**
Windrow System			
Site Preparation and Capital Purchases[b]	$804,000 ($217/ton)	$880,000 ($129/ton)	$1,784,000 ($59/ton)
Operating & Maintenance of Composting Facility	$582,000 ($157/ton)	$1,006,000 ($148/ton)	$4,057,000 ($135/ton)
Excavation and Backfill	$42,000 ($11.40/ton)	$78,000 ($11.40/ton)	$342,000 ($11.40/ton)
Total Facility Costs	$1,430,000 ($386/ton)	$1,960,000 ($288/ton)	$6,180,000 ($206/ton)
MAIV System			
Site Preparation and Capital Purchases[b]	$1,409,000 ($381/ton)	$1,483,000 ($218/ton)	$2,314,000 ($77/ton)
Operating & Maintenance	$963,000 ($260/ton)	$1,705,000 ($251/ton)	$7,257,000 ($242/ton)
Excavation and Backfill	$42,000 ($11.40/ton)	$78,000 ($11.40/ton)	$342,000 ($11.40/ton)
Total Facility Costs	$2,410,000 ($651/ton)	$3,270,000 ($481/ton)	$9,910,000 ($330/ton)

Notes: For cost-effectiveness, the windrow system used to treat the soil from a 20-foot excavation is assumed to be twice the size of the system used for a 2-foot excavation. While this increases capital costs, the increase is more than offset by a decrease in O&M costs.
[a]Average excavation depth. Actual depth at individual locations in lagoons may vary.
[b]Capital costs adjusted for 7-year straight-line depreciation.

Site Preparation and Capital Equipment Costs. Site preparation includes advance planning and management; detailed site design and development (e.g., access roads,

clearing, surface construction); utilities connections; facility construction (e.g., construction of the MAIV reactor or windrow shelters); and site support staff.

Area and surface foundation requirements were described in Section 4.2.4.2. The required area would be cleared of existing vegetation, surveyed, graded, and compacted. An asphalt foundation would be prepared to support the Sprung structures or MAIV reactor, and to provide stockpile and mixing areas for contaminated soil, amendment, and finished compost. Graded and graveled areas would be constructed for auxiliary equipment (e.g., vehicle storage, personnel trailers, portable laboratory). Gravel roads sufficiently wide to accommodate construction equipment would be installed between existing roads, the lagoons, and the composting area.

Electrical cable and appropriate auxiliary equipment would be installed to tie in to the existing UMDA power supply. Temporary piping would be installed to provide water service from the UMDA hydrant system. A fire control system, including pipes and a pump, would be installed for the active compost areas as required by state solid waste regulations.

For the MAIV system, additional site preparation costs would be incurred constructing the concrete vessel for the reactor and installing additional utilities. These non-recoverable costs were estimated by the vendor at $500,000 (Fairfield Service Company, 1992).

Major equipment purchases for a 3,700- to 6,800-ton windrow composting facility would consist of the following:

- Sprung structures (4) - $166,000 each, delivered (Sprung Instant Structures Inc., 1991)

- Windrow turner (1) - $180,000 delivered (Scarab Manufacturing and Leasing, Inc., 1991)

- Front-end loader (1) - $120,000 delivered

- Haul truck (1) - $80,000 delivered

The specified number of equipment items would double for the larger windrow facility assumed to be constructed for the 30,000-ton case. The equipment costs were adjusted in the overall site preparation costs to reflect a salvage value based on an estimated economic life of 7 years using straight-line depreciation. Consideration could also be given to leasing rather than purchasing the equipment. However, for the length of use contemplated, purchase would be more cost-effective.

Major equipment purchases for a MAIV composting facility would consist of the following:

loader). Based on continuous use of the equipment during facility operating hours (40 hours per week) and standard fuel usage and maintenance rates, the equipment O&M costs were estimated to be $96 per hour, or $3,800 per week, for the 3,700- to 6,800-ton facility. Costs would double for the 30,000-ton facility.

Six full-time employees would be the minimum required to operate the 3,700- to 6,800-ton windrow composting facility. These include operators for the windrow machine, front-end loader, and haul truck; a maintenance mechanic; a project engineer; and a staff assistant. Weekly labor costs would be about $5,300, including fringe benefits and the OSHA hazardous waste site training and medical evaluations required under 29 CFR 1910.120. Labor costs would approximately double for the 30,000-ton windrow composting facility.

Total labor and equipment O&M costs for the windrow facility would be as follows:

- 3,700 tons (32 weeks) - $295,000
- 6,800 tons (54 weeks) - $488,000
- 30,000 tons (109 weeks) - $1,999,000

The purchase of organic amendment, assumed to be a mixture of cow manure and vegetable waste, would be added to these costs. Assuming a cost of $50 per ton for the amendment, an amendment density of about 900 pounds per cubic yard, and a

volume ratio of 4 parts amendment to 1 part soil, the cost of purchasing amendment would be $62 per ton of loose soil processed.

O&M costs for an MAIV composting system are dominated by the costs to operate and maintain the reactor vessel, including the blower, turning and mixing motor, conveyors, and top cover (which rotates the mixing augers). The hourly cost (40-hour-per-week active operation) is estimated to be $440, including operators, electricity, parts, supplies, vendor-supplied maintenance support, and labor for repairs. This cost was derived from actual costs incurred for a comparably-sized unit in operation at the Plattsburg, New York, sludge composting facility, excluding costs for the extensive odor control system required at Plattsburg.

Additional equipment O&M for rolling stock (front-end loader and haul truck) is estimated to be $29 per hour, or $1,160 per week. Additional staff costs (solids handling equipment, project management, maintenance and support staff) are estimated to be $5,300 per week (it is assumed that MAIV operator training is included in the $440/hr cost for the MAIV).

Total labor and equipment costs for the MAIV operation would be as follows:

- 3,700 tons (28 weeks) - $683,000
- 6,800 tons (50 weeks) - $1,194,000
- 30,000 tons (207 weeks) - $5,022,000

As with the windrow facility, the cost of amendment would be an additional $62 per ton of loose soil processed.

For all composting scenarios, samples would be required from both the excavated soil prior to mixing and the finished compost. Samples would be analyzed for explosives to verify that the RAOs have been achieved. A detailed sampling plan would be developed as part of the remedial design, but it is assumed that a portable laboratory would be set up onsite to perform the necessary analyses. Daily soil samples could be combined into one weekly sample for analysis. Estimated weekly costs for these analyses are $1,800, including labor and materials. This estimate is consistent with costs incurred during other close-support laboratory operations.

4.2.4.4 Summary

A summary of the NCP criteria evaluation is provided in Table 4-8. Composting using a windrow system would be a cost-effective method for reducing explosives concentrations and toxicity in the contaminated soil to acceptable levels. Concentrations of TNT and RDX would be decreased from their present levels (100 to 88,000 μg/g) to 30 μg/g or less each. The total excess cancer risk to an individual exposed to the composted soil would be reduced to 7.2×10^{-6} (light industrial use scenario) and 1.8×10^{-5} (residential use scenario). This level of protection could be achieved for a total estimated expenditure of $1.96 million, assuming an excavation 5 feet below the bottom of the lagoons.

Table 4-8
Summary of NCP Criteria Evaluation for Windrow Composting Alternative

Effectiveness						
Overall Protection	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction of Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Implementability**	**Cost**
Protection of human health achieved through degradation of explosives to protective levels (excess cancer risk 1.8×10^{-5}, residential use scenario). Protection of environment achieved by reducing plant stress associated with high explosives concentrations.	Accomplished by reduction of contaminants to protective levels using cost-effective methods.	Effectiveness is expected to be long-term, since degradation products either mineralize or bind covalently into macromolecules. Contaminant concentrations reduced 97 to 99%.	Composting reduces soil toxicity as measured by bacterial mutagenicity and aquatic toxicity by 88 to 98%. Residual material is nutrient-rich compost. No other waste streams are produced.	Protection of workers, environment, and community during operations is accomplished with proper safety procedures and process monitoring. Time to implement and complete remediation 20 to 36 months.	Composting is commonly used in other applications. Site-specific treatability studies indicate successful application to UMDA soil and con-taminants. Materials of construction and compost amendments readily available in area.	2-ft. excavation: \$1,430,000 5-ft. excavation: \$1,960,000 20-ft. excavation: \$6,180,000

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The windrow facility concept developed for this analysis was based on efficiently using the minimum equipment required to complete the job. Sensitivity analysis showed that the windrow-turning machine utilization approximated system efficiency. Therefore the facility was sized to operate efficiently using one windrow-turning machine at a 90 percent availability.

Composting using an MAIV system appears not to be cost-effective. As indicated in Tables 3-6 and 4-6, MAIV composting conducted under optimal conditions can reduce TNT and RDX concentrations to the range of 5 to 20 µg/g. This additional reduction is generally less than 5 percent of the total contaminant degradation anticipated. For this additional reduction, the total cost of the MAIV system is significantly higher than for a windrow system, 70 percent higher in the case of the 5-foot excavation.

4.3 Comparative Analysis of Alternatives

Table 4-9 presents an evaluation of the residual risks and costs associated with different excavation depths and technology alternatives.

Table 4-10 provides a comparative evaluation of the degree to which each remedial technology alternative meets the selection criteria.

Table 4-9
Cost and Effectiveness of Alternatives as a Function of Excavation Depth

Alternative	Mass (tons)	Excess Cancer Risk Prior to Remediation[a]		Excess Cancer Risk Following Remediation[a]: Excavated/Treated Soil		Excess Cancer Risk Following Remediation[a]: Soil Remaining Below Excavation Depth[d]		Total Cost ($000)	Cost (present worth, $000)
		Industrial Use Scenario	Residential Use Scenario	Industrial Use Scenario	Residential Use Scenario	Industrial Use Scenario	Residential Use Scenario		
No Action	NA	4.7×10^{-3}	1.0×10^{-2}	NA	NA	4.7×10^{-3}	1.0×10^{-2}		0
Incineration									
2-foot excavation	3,700	4.7×10^{-3}	1.0×10^{-2}	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	8.0×10^{-5}	2.1×10^{-4}	2,730	2,540
5-foot excavation	6,800	4.7×10^{-3}	1.0×10^{-2}	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	7.2×10^{-6}	1.8×10^{-5}	4,470	4,120
20-foot excavation	30,000	4.7×10^{-3}	1.0×10^{-2}	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	7.2×10^{-6}	1.8×10^{-5}	8,290	7,650
47-foot excavation[b]	47,000	4.7×10^{-3}	1.0×10^{-2}	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$	14,000	12,800
Composting—Windrows									
2-foot excavation	3,700	4.7×10^{-3}	1.0×10^{-2}	7.2×10^{-6}	1.8×10^{-5}	8.0×10^{-5}	2.1×10^{-4}	1,430	1,370
5-foot excavation	6,800	4.7×10^{-3}	1.0×10^{-2}	7.2×10^{-6}	1.8×10^{-5}	7.2×10^{-6}	1.8×10^{-5}	1,960	1,870
20-foot excavation	30,000	4.7×10^{-3}	1.0×10^{-2}	7.2×10^{-6}	1.8×10^{-5}	7.2×10^{-6}	1.8×10^{-5}	6,180	5,590
47-foot excavation[c]	NA	4.7×10^{-3}	1.0×10^{-2}	NA	NA	NA	NA	NA	NA
Composting—MAIV									
2-foot excavation	3,700	4.7×10^{-3}	1.0×10^{-2}	$<7.2 \times 10^{-6}$	$<1.8 \times 10^{-5}$	8.0×10^{-5}	2.1×10^{-4}	2,410	2,320
5-foot excavation	6,800	4.7×10^{-3}	1.0×10^{-2}	$<7.2 \times 10^{-6}$	$<1.8 \times 10^{-5}$	7.2×10^{-6}	1.8×10^{-5}	3,270	3,100
20-foot excavation	30,000	4.7×10^{-3}	1.0×10^{-2}	$<7.2 \times 10^{-6}$	$<1.8 \times 10^{-5}$	7.2×10^{-6}	1.8×10^{-5}	9,910	8,200
47-foot excavation[c]	NA	4.7×10^{-3}	1.0×10^{-2}	NA	NA	NA	NA	NA	NA

[a]Risk based on direct contact with soil: ingestion, inhalation, dermal contact.
[b]This scenario reflects cleanup to background. All contaminated soil would be treated.
[c]A combination of composting and a 47-foot excavation was not evaluated. The deep excavation is intended to reflect cleanup to background and cannot be achieved by composting.
[d]Risk calculations based on average TNT, RDX, and 2,4-DNT concentrations measured at indicated depth.
NA = Not applicable to this alternative.
cy = Cubic yards.

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Table 4-10
Comparative Evaluation of Alternatives

Effectiveness						
Overall Protection	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction of Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Implementability**	**Cost**
Alternatives 2 and 3 provide overall protection of human health and the environment in accordance with the NCP by reducing the excess cancer risk to $<1 \times 10^{-6}$ and 2×10^{-5}, respectively (residential use scenario); both significantly reduce plant stress associated with very high explosives concentrations; some reduction in growth height may still be observed in Alternative 3. Alternative 1 provides no protection for future users of the site, does not enhance protection of the environment, and is not addressed further in this table.	Alternatives 2 and 3 comply with all ARARs. In accordance with state requirements for remedial actions, the risk reduction benefits for variations on each alternative are shown as a function of cost.	Long-term effectiveness is achieved in Alternative 2 by the permanent destruction of 99.99 percent of contaminants. Alternative 3 achieves long-term protection by degrading contaminants by 97 to 99 percent.	Excavation to 5 feet below the lagoons reduces excess cancer risk by about 99.8 percent from initial levels. This increases to 99.9 percent at 20 feet and 100 percent at 47 feet. Both Alternatives 2 and 3 reduce contaminant concentrations in excavated soils, thereby reducing toxicity. Alternative 2 reduces toxicity by >99.99 percent. Alternative 3 reduces toxicity by 88 to 98 percent.	Both Alternatives 2 and 3 use appropriate controls to provide near-term protection of the public, onsite workers, and the environment during remedial activities. Alternative 2 could be implemented and completed within 15 to 19 months. Alternative 3 could be implemented and completed within 20 to 36 months.	Implementability of Alternative 2 has been demonstrated for similar contaminants at other sites. Alternative 3 is innovative, but supported by site-specific treatability studies. There appear to be no obstacles to obtaining necessary materials and agency approval.	Costs for a 47-foot excavation with treatment by incineration (Alternative 2) (cleanup-to-background) are $14 million. For other excavation depths, Alternative 3 is less expensive, especially for low volume remediation (e.g., for a 5-foot excavation, costs are $2 million for composting versus $4 million for incineration.)

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As the tables show, Alternative 1, No Action, provides virtually no protection of human health and the environment and fails to meet ARARs. Alternatives 2 and 3, Incineration and Composting, provide tradeoffs between degree of risk reduction and total remedial action cost. Alternative 2 provides greater risk reduction than Alternative 3, but at approximately twice the present-worth cost for a given excavation depth. An excavation depth of 5 feet below the lagoons provides the greatest percent risk reduction while achieving ARARs. The most aggressive alternative, a combination of incineration and an excavation to the water table, would be comparable to a cleanup to background, but at a present worth cost 7 times greater than a combination of the 5-foot excavation and composting.

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